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Physics at Wellesley

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IN the eighteen seventies Wellesley was almost alarmingly progressive. Mr. Durant, a Harvard graduate, had founded the college with the avowed purpose of offering to young women an education equal to that given young men at his alma mater. Since one of his beliefs was that women were peculiarly gifted as teachers, the first faculty of the college was composed, with but one exception, the professor of music, of women. In those days college-trained women were few and far between, but the few there were had the spirit of pioneers. For those first professors Mr. Durant combed the country and assembled a remarkable group of ardent young women scholars, who embarked with enthusiasm upon the venture of making Wellesley the equal of the best colleges for men. Not all held college degrees. In several instances he found young teachers of promise and offered them the opportunity for further training. Among these latter was Sarah Frances Whiting, who, after her appointment in 1876, studied at the Massachusetts Institute of Technology as a guest of the Institute and of Professor Pickering. Under her direction the physics laboratory at Wellesley was opened in 1877, one of the very earliest in the country in which physics was taught by laboratory methods.

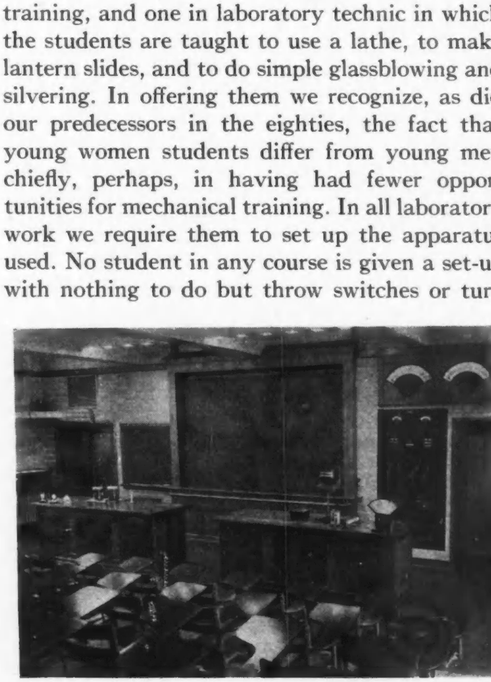
The equipment was as advanced as the methods of teaching. In 1876 there were no large manufacturers of apparatus in this country and no catalogs of foreign instrument makers available, but in the company of Professor Barker of Pennsylvania, Miss Whiting visited the centennial exposition in Philadelphia where were exhibits by Duboscq, König and others. Apparatus was ordered from England, France and Germany. There were König tuning forks and organ pipes, a Meyerstein spectrometer, a set of crystals for the study of polarized light from Hofmann of Paris, a Browning spectroscope "giving a dispersion of twelve prisms," a Thomson mirror galvanometer made by Elliot of London. The apparatus to accompany Pickering's *Manual* was largely made to order by Boston mechanics. Among the scientific periodicals in the department library were the Comptes rendus and the Philosophical Magazine. Complete files of such journals as the Proceedings and Transactions of the Royal Society were early acquired.

Courses in the early years were few. In the first calendar but one course is described, but the students are informed that "large working laboratories are provided . . . in which they will be required to become practically acquainted with the use of the instruments and methods of physical investigation." A second course, largely laboratory work, was offered in 1878–9. Gradually the courses grew in number and variety. In 1887, to meet the objection that young ladies could not use tools, a course in the construction of instruments was offered, but by 1891–2 a course in the theory of electricity and of light with analytical geometry and calculus as prerequisites had usurped its place. One is left to

Front view showing entrance to lecture hall.

wonder whether the students of those days showed that they had no need for such practical training or, on the contrary, too little aptitude to make it worth while. In 1889–90 a course in meteorology was introduced; in the early nineties, sound was offered for the music students and, for one year, physical chemistry, taught by Professor Margaret Maltby, later of Barnard. By this time there were seven courses.

The problems of a department of physics in a liberal arts college differ in many ways from those of a department in a large university. The students are on the average no less able but from a group of fifteen hundred one cannot expect as many major students as from five thousand; there are also fewer taking graduate work. For these reasons there is less opportunity for the highly specialized courses. The emphasis must be upon sound training in general physics. Wellesley offers only fifteen courses aggregating some fifty semester-hours. Those fifteen courses must meet the needs not only of the major students but of the future chemists, physicians and biologists, and of the nonscientific students who would know something of modern physics. It is our belief that general physics should form a part of a liberal education but that the cultural aspects should be emphasized only insofar as they are compatible with thorough training. The better to adapt the elementary work to the students of varying needs, three courses in general physics are offered: one, the most commonly elected, for students who have had no mathematics beyond algebra and geometry; a second for students who are taking mathematics; a third for those who have had secondary school physics. In these courses the students are divided into sections of about twenty. The lectures are exceedingly informal and the students are encouraged to interrupt with questions. The small size of the classes permits them to see and examine the apparatus. For the laboratory work the sections are even smaller. No more than sixteen are assigned to one instructor. Each student works alone. The elementary courses are followed by a group of intermediate courses in electricity, atomic physics, sound, light, and meteorology, open to students who may not have the mathematics essential for a major in the department. Of these, all but the course in atomic physics have laboratory work. For the major students there follow courses in mechanics, in the principles of radio communication, and in theoretical electricity. Beginning with 1936–7 there is to be also an advanced laboratory course in atomic physics. Among the courses are two not usual in liberal arts colleges, one in the physics of the automobile, introduced during the war in response to a demand for practical training, and one in laboratory technic in which the students are taught to use a lathe, to make lantern slides, and to do simple glassblowing and silvering. In offering them we recognize, as did our predecessors in the eighties, the fact that young women students differ from young men chiefly, perhaps, in having had fewer opportunities for mechanical training. In all laboratory work we require them to set up the apparatus used. No student in any course is given a set-up with nothing to do but throw switches or turn

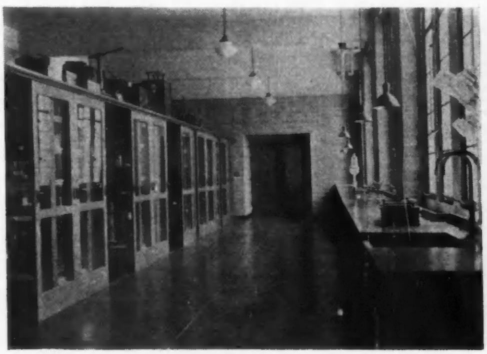


Small lecture room.

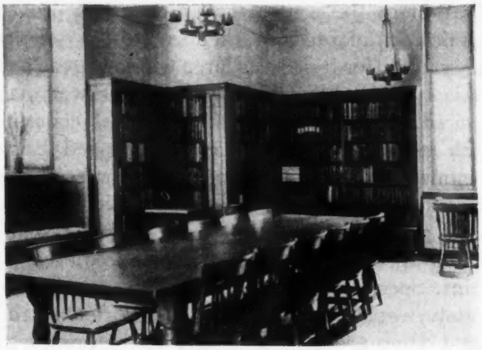
micrometer screws and take readings. In optics, for example, they make all adjustments on the spectrometers; in the radio laboratory they set up the circuits for taking characteristic curves and are expected to choose meters and rheostats of suitable ranges. The sacrifice of a few experiments is more than offset by the sense of mastery gained.

Since 1922, when a system of "honors in subjects" was established, the department has offered independent work to qualified undergraduates who desire to work for honors in physics. More recently this privilege has been extended to all major students. If the number of major students is necessarily small, that very fact gives the greater chance for individual guidance to the few who wish to make physics their profession. I think as I write of successful college teachers, of a young radio engineer, of a patent attorney specializing in radio, of a recent graduate who is writing popular articles on science, as well as of the successful teachers in secondary schools.

The graduate students are usually department assistants who spend two years in preparation for the master's degree and at the same time gain valuable experience by laboratory teaching. They are usually expected, in addition to taking course work, to write a thesis based on research. Until this year lack of space and other facilities have made research for members of the staff and graduate students difficult. Nevertheless for some years an investigation of the dielectric properties of glass has been in progress. At present two members of the department are working in



Central apparatus room.



The Sarah Frances Whiting Memorial Library.

collaboration with groups at Harvard and the Massachusetts Institute of Technology on problems in x-rays and cosmic rays, respectively.

For many years the department has been handicapped by lack of an adequate laboratory. Since the possibility of laboratories for the teaching of physics was just beginning to be thought of in 1875 when College Hall, the original main building, was opened, it is not strange that, despite Mr. Durant's progressive attitude, the first physics lecture room was in the attic and the laboratory was approached through the trunk room. Gradually the department acquired additional space, but in 1914, fire destroyed College Hall, and with it the physics laboratory and equipment. The college made generous appropriations for new equipment but laboratories cannot be conjured overnight out of thin air. The chemistry department offered the hospitality of an already overcrowded building and after two years the department acquired part of what had been the service wing of College Hall and turned kitchen, pantries and even the coal cellar into laboratories and lecture rooms. While making shift with these quarters we began to draw plans for a new laboratory but not until 1934 was the corner stone of the building, Pendleton Hall, actually laid. The physics laboratory occupies three floors of the east wing. Above is psychology and in the west wing, separated by a large lecture hall, chemistry. In planning, three principles were kept in mind: convenience of arrangement, completeness of equipment, and comfort of the users. The style of architecture, modified collegiate Gothic, was imposed by the

location in the central group, but has proved admirably adapted to the needs of a science laboratory, for it permits large window areas and makes it possible to place partitions wherever desired. The building is of reinforced concrete with exterior walls of water-struck red brick trimmed with Indiana limestone. For economy the exterior detail was greatly simplified and the inner partitions made of "travablock," a semi-glazed tile, in a light buff, which requires no paint. Special care was taken to insure a completely water-tight building. In addition to the usual damp-proofing below grade, the brick was selected after a series of tests for quantity and rate of absorption, strength, and homogeneity. A mortar with sufficient lime to make the differential shrinkage as low as possible was then designed for the particular brick chosen. The college was fortunate in having the expert advice of Professor W. C. Voss of the Massachusetts Institute of Technology who is carrying on research in building construction and is an authority on masonry materials.

The net floor area of the physics laboratory exclusive of corridors but including the central lecture hall, which seats 400 and is used by all departments, is about 22,000 ft.^{2}. The ground floor contains machine and wood shops, in charge of a mechanician, 7 research rooms, 3 advanced laboratories, photographic dark rooms, glass-blowing room, a small chemical preparation room and the switchboard, generator, transformer and battery rooms. On the first floor are 2 offices, library, staff room, 2 lecture and 3 classrooms, with a centrally located apparatus room. On the second floor are the elementary laboratory and laboratories for optics, electricity, and meteorology, with connecting offices.

Especial thought was devoted to convenience in handling apparatus. The receiving and unpacking room is directly underneath the main apparatus room and adjacent to the elevator shaft, which has doors opening into both rooms as well as into the corridors. The apparatus room connects the two lecture rooms and is directly across the corridor from the three classrooms. The apparatus case, fitted with glass sliding doors, has adjustable shelves extending out from the wall, separated by wide floor spaces, so that tables can be rolled directly to the shelves. Dome lights give excellent illumination. The laboratory apparatus is housed in a small, similarly arranged apparatus room on the second floor and in cases in the laboratories where it is readily accessible.

The electrical distribution system is especially flexible. From the main distributing board numbered lines run directly to all ground floor rooms and to five panels supplying lecture rooms, classrooms and laboratories. Generators supply 110 and 400 volts d.c., 115 volts a.c. and 230 volts, 2-phase a.c.; three storage batteries furnish constant voltages in steps of 4 or 6 volts to 24 volts, 2 volts to 120 and 12 volts to 720. Time signals of 1 sec., 10 sec., etc., can be transmitted to any room. Provision is made for the later installation of a 1000-cycle oscillator.

Lecture tables have the usual gas, compressed air and vacuum connections, ground wires, and 110-volt a.c. receptacles as well as the multi-potential outlets. In addition there are receptacles connected to the 110-volt generator through a fixed rheostat, for the direct connection of small arc lamps. One novelty is a sink in which the disappearing pantry cocks are so placed that there is a clear height of five inches above the cocks, into which fits either a removable electric heater with an open wire mesh top to dry the apparatus used in electrostatic experiments or an illuminator with ground glass top.

In the corridor opposite the meteorology laboratory there are installed an anemograph to give a continuous record of the direction and

Elementary laboratory.

speed of the wind, and a recording mercury barograph. A Foucault pendulum shaft utilizes a waste corner in the stair halls.

In planning the building we remembered that human beings are more precious and less replaceable than equipment, and also that physicists should lead the way in applying the discoveries physicists have made. For the comfort of students and staff all lecture and class rooms, corridors, offices and certain laboratories have ceilings of "sanacoustic" tile. In lecture and class rooms there are posture chairs which are pronounced really comfortable by nine out of ten users. (Members of the department sat in 57 varieties before deciding on these.) Forced ventilation removes one excuse for falling asleep. Dim lights permit the taking of notes when pictures are being shown; at other times ample light without glare lessens eye-strain. Motor-driven blackboards and shades make the lecturer's life easier. An inter-communicating telephone system with seventeen stations saves many steps. In convenience of arrangement and comfort the building more than fulfills our expectations.

The future of physics at Wellesley depends now on the use the department makes of the excellent facilities at its disposal.

Reminiscences of a Scientific Comradeship

Gordon Ferrie Hull, *Dartmouth College, Hanover, New Hampshire*

To the request of the Editor of *The American Physics Teacher* for an account, historical, personal, in retrospect, concerning conditions connected with the measurement of the pressure of light, I respond the more readily since it offers me an opportunity again to pay tribute to the memory of Ernest Fox Nichols.

To get the proper perspective we must go back to the closing decade of the nineteenth century. Maxwell's electromagnetic theory appeared to be the Final Word concerning the nature of light. Its brilliant confirmation by Hertz in the matter of electric waves made it the supreme contribution to physics since the early days of Faraday. So completely did theory and experiment unite to give a satisfying picture of many optical and electromagnetic phenomena that physicists in various parts of the world were in accord with the view, as expressed in a bulletin sent out in 1895 by a famous graduate school in physics—"It seems probable that most of the grand underlying principles of physics have been established." This view was soon to receive some severe shocks, however, for in 1895 x-rays were discovered, in 1896 Becquerel rays, in 1897 the electron, in 1898 radium, and in 1900 the first proposal was made that led to the quantum theory. It is interesting to note that all of these discoveries were made in Europe; America did not participate in one of them. As an evidence of a changed world we record that in 1932, for example, there were three great discoveries in physics, with the positron and heavy hydrogen belonging to America, the neutron to Europe. America is growing up.

While it is clear that in the closing years of the nineteenth century American physicists were very far from being in the van, American astronomers, on the other hand, occupied a prominent position. The invention of the spectroheliograph, the development of astrophysics, the building of great observatories, all contributed to this result.

It was at the dedication of the Yerkes Observatory in October 1897 that I first met Ernest Fox Nichols. While several of the leading scientists present were guests in the homes of the Observatory staff most of the delegates were domiciled in the observatory. The few days we spent there were days of close association. We were a congenial, isolated group. It was much like being on an ocean liner; we quickly became acquainted. I recall in passing that this was my first experience, outside of a Pullman, with sleeping arrangements in the form of two- or three-decker beds. It was not entirely due to my reverence for age that I suggested to a 250-pound astronomer who drew the berth above mine that we exchange berths. The new arrangement was mutually satisfactory.

In the previous year Dr. Nichols had returned from Berlin where (with Rubens) he had been concerned with experiments on so-called long heat waves. He had pushed out the measured wavelength to 23μ. He had also been interested in the application of the electromagnetic theory to the phenomena of dispersion. I had just published an elementary study of the interference of short electric waves and it was natural that we should be drawn together by our mutual interests in those closely related phenomena which, at that time, were separated by a small gap. We discussed the outstanding problems of Maxwell's theory, little thinking that we might have an opportunity to work on that prophesied property of light which seemed so difficult to obtain—the demonstration and measurement[1] of its pressure. It may be recalled that Maxwell,[2] after computing the pressure that should be exerted by sunlight, stated that it was entirely too small to be measured. Also Drude, in his important text on *Physical Optics*, published in 1900 (the translation by Mann and Millikan appeared in 1902) made the same statement.

The following year, 1898, Dr. Nichols left Colgate for Dartmouth and a year later I joined him. The Wilder Laboratory had just been completed. New apparatus had to be purchased and installed, new courses of instruction had to be arranged. The new laboratory and teaching personnel brought greatly increased enrollment in physics and the two of us, each with an assistant, spent full days on duties connected with teaching. But we found some time to assemble apparatus for the attempt to measure the pressure of light.

The living arrangements in Hanover 36 years ago were limited and it was a great satisfaction to me that the Nichols were kind enough to include me in their household during my first year there. For me it was a never-to-be-forgotten year. The mistress of the home was and is a lady of dignity and charm. She had been with her husband during those years in Germany and knew many eminent scientists there. She was a gifted conversationalist. After dinner round the fireplace before Dr. Nichols and I went to the laboratory for our night's work there frequently were readings from our favorite authors. Dr. Nichols had an unusually keen appreciation for good literature and though he had studied neither Latin nor Greek he had a rather wide knowledge of the classics in translation. Although I had studied both languages, he introduced me to some of these translations, to the writings of Robert Louis Stevenson, to some of Kipling's *Plain Tales from the Hills*. My contributions were of a lighter vein: Mark Twain, Kipling's poems, the *Bab Ballads*, Dr. Drummond's French Canadian poems (in dialect).

Mrs. Nichols frequently acted as our assistant during an experimental run at night. Her duties were to throw various switches at the proper time. But though the spirit was willing, the flesh, towards midnight, became sleepy. When we would call "throw," sometimes nothing happened. "Asleep at the switch" came to have for us a special significance.

During the summer vacation of 1900 Professor Nichols was at the Yerkes Observatory measuring the radiant energy from Arcturus, Vega, Saturn. I remained in Hanover and set up the torsion balance used in the experiment. Quartz fibers had to be made. This was not an exact science. They were caught on black velvet as they were blown away from an oxyhydrogen flame. Then from the maze of fine and coarse fibers one was selected that was thought to be suitable. But the first fibers used were entirely too fine. However, the early suspensions, being sensitive, showed up gas action or radiometric action. By the end of the summer it was seen that the pressures in the bell jar ought to be within certain limits and this led at once to the study of gas action at different pressures. It will be recalled[3] that we worked at a pressure which, for the suspension used, made the gas action a minimum.

The early devices for measuring the energy of the light were of the bolometric type. A very special technique was required for mounting and covering with platinum black a sheet of platinum one-thousandth of a millimeter in thickness. Dr. Nichols had mastered this technique in Berlin where it was much in vogue. It appeared to me

[1] For full sunlight the pressure is nearly 10^{-4} dyne/cm^2.
[2] J. C. Maxwell, *Electricity and Magnetism*, ed. 3 (1892), vol. II, p. 441.

[3] Phys. Rev. **17**, 44 (1903).

to be an operation requiring the utmost skill in dealing with extremely thin sheets of metal. Yet in the experimental work of today physicists are accustomed to use sheets of gold or of platinum of 10^{-5} mm in thickness!

This brings to mind other contrasts between former and present facilities. We had to work with a flickering, shifting arc lamp; the tungsten filament lamp was unknown. We had to raise a heavy jar full of mercury up and down many times in order to get a moderate vacuum; modern vacuum pumps were unknown. Galvanometers have been greatly improved, photronic or photoelectric cells have been adapted for the relative measurement of the intensity of light; new apparatus and new phenomena of physics have marched forward together.

There were certain assumptions in our work which at first appeared to be entirely correct but which, towards the end of the experiment, were found to be in error. It was assumed, for example, that the reflection coefficient for light reflected from silver in air was the same as that for silver on the rear face of a glass plate and this of course led to the view that the absorption in the two cases was the same. There were no *International Critical Tables* to give such data. Landolt and Börnstein, the standard tables of the time, gave no information on this point. But we found experimentally that the absorption for the glass-silver surface was three or four times that for the air-silver surface. Consequently our plausible assumption that the gas action, when we reversed the glass vane, would be equal and opposite to its value for the first position was incorrect. We were working, however, in a pressure region in which the gas action was very small and slightly variable from day to day. By reversing the vane we got more readings with a consequent decrease of statistical variations.

In our first paper,[4] which appeared in 1901, we reported that the value of the pressure of our standard light beam as measured by the torsion balance differed from the value computed from the energy as measured by our bolometer by about 20 percent. This included, however, data taken at air pressures varying from 96 to 0.06 mm. We knew beyond question that considerable gas action was present at some of these pressures. Had we limited our data to those pressures for which it was known that the gas action was small, the discrepancy would have been of the order of 10 percent. Moreover, in that report we assumed that the reflection coefficient of light reflected from glass-silver was 92 percent. Later when the true value of this coefficient had been measured and when corrections due to errors in some of our constants were applied, the torsion balance and the energy values of the pressure agreed. In other words, had we measured the reflection coefficient for glass-silver before our 1901 report and used correct constants referred to below we would have confirmed Maxwell's theory in our first report, within our experimental error which was a few percent. But an accident to our bolometer caused us to change to the silver disk-thermojunction method of measuring the intensity, with an apparent decrease in the experimental, but an actual increase in the constant, error.

In the tens of thousands of computations which we made during those three years of work there were two determinate errors, and probably only two, both of which were exposed to public gaze in our final report. We made an error of nearly 2 percent in writing down and using the mechanical equivalent of heat and we dropped out of our computation a factor $e^{-\gamma t}$ in computing the constant by which the ballistic throws were reduced to static deflections. It is past understanding that these errors should have escaped detection by us and by hundred of others who must have read our report within a few years after publication. However, the corrections when properly applied bring into agreement the pressure as measured by the torsion balance and the energy density as measured by the bolometer. They threw out of agreement the torsion balance pressure and the silver disk measurements by an amount of nearly 7 percent. The corrections, too, show that we had not succeeded in measuring by the silver disk the absolute value of the energy density of our light beam to an accuracy of 1 percent—as our final report indicated we were doing.

While it may appear ungenerous to compare with our results those found by Lebedew[5] and published at the same time as our first report,

[4] Phys. Rev. 13, 307 (1901); A. A. A. S., Denver, August, 1901.

[5] P. Lebedew, Ann. Phys. 6, 433 (1901).

still it may serve to show that it was not easy at that time to measure these quantities with accuracy. Lebedew had discrepancies as great as 80 percent between the two values of the pressure. Another example is the accuracy obtained in the measurement of a quantity dependent upon the intensity of radiant energy, the Stefan-Boltzmann constant in the relation $E=\sigma T^4$. Of 21 measurements since 1909, as given in the *International Critical Tables*, only four can claim an accuracy of 1 percent. Coblentz, with the excellent equipment of the Bureau of Standards available and after ten years of labor on this kind of problem, made the first of these measurements in 1915. Three others have been made in the past few years. The density of radiant energy which we thought could be easily and accurately determined was the quantity which involved the greatest difficulty in measurement.

The silver disk measurements of energy density were beautiful in their uniformity. This uniformity and their very satisfactory agreement with the pressure as we computed it from our measurements disarmed us as to criticism. It did not seem possible that chance could have brought about an agreement in two values which contained compensating errors. But the bolometer measurements of energy density now came in to give a very close agreement between the two sets of measurements.

Into a supplemental part of the work on light pressure we entered in a spirit of play. It will be recalled that we arranged a qualitative experiment for simulating the phenomenon of a comet's tail. By good luck we found in the Science Museum a huge puffball—about a foot in diameter. This provided us with a large amount of puffball spores. These were heated under partial vacuum until it was thought that all vaporizable material had been driven off. Then the fine particles, now hollow shells, were placed in a glass tube in the form of an hour glass, and again heated while the vacuum was pushed to the limit of our pump. (As has been indicated previously, to "push" a vacuum to a limit had a significance then that it has since lost. It meant "lifting"; it meant labor. The pumping out of a "comet's tail" tube required continous heating and pumping for many hours.) When an intense horizontal beam of light was thrown on the stream of falling particles they were deflected away from the light source as if they were particles in a comet's tail. At first it looked as though the deflection was the right amount to be ascribed to the action of the light pressure.[6] Had we been content with the first two tubes our conclusion would have been reasonably justified. But in the third tube the particles were driven strongly away from the light source. The force on a particle must have been at least ten times as great as that due to light pressure. Apparently gas was being driven out of the particle on the side towards the light. Presumably this resulted in a rocket action on the particle. If such an action could take place in this tube it might be present to a smaller extent in the first two tubes. Perhaps there was gas action or rocket action in all of the tubes. But the falling stream of particles could be made to resemble a comet's tail.

After we had finished the work on light pressure our attention was turned to other experiments, several of which we had planned. One of these we definitely expected to carry through during the summer vacation of 1903. But before starting work we felt it necessary to get a rest after a heavy college year. We started on a two weeks' vacation to be spent in climbing and tramping in the White Mountains. In those days maps of the mountain region were very incomplete and the trails were poorly marked. We got lost the first day; that is to say, we got on the wrong trail in our attempt to climb Mt. Moosilauke. Finally the wrong trail became no trail whatever. But in an attempt to retrace our steps we came across a trail that looked promising. We climbed rapidly and reached the summit at nightfall—having spent almost the entire day on a climb that should have taken only three hours. It was upon that climb that I became aware of the physical ailment which later was the cause of Dr. Nichols' untimely death. His heart could not stand prolonged strenuous exertion or undue excitement. We climbed some of the chief mountains, including the Presidential Range; we explored some of the unusual features of the region, notably the Lost River formation, then practically unknown, now visited by hundreds of

[6] E. F. Nichols and G. F. Hull, Astrophys. J., **17**, 352 (1903); G. F. Hull, Trans. Astron. Soc. Toronto, p. 123 (1901).

tourists a day. We returned to Hanover with tanned faces, hirsute adornments, tired bodies, and rested minds.

The experiment upon which we planned to work during the summer was another which seemed to lie in the optical-electromagnetic border-land. We proposed to look for a mechanical or electromagnetic resonance for light waves. I had found, as had others, this effect in the region of electric waves. Dr. Nichols while in Berlin had secured some preliminary data in the region of light. We would throw light of various wave-lengths, including the long infrared, upon metallic rectangles. In our case gold films deposited on glass had been cross-ruled into rectangles of the order of 0.005 mm in length. We expected to find that certain wave-lengths would be copiously reflected. We found definite pronounced maxima in the reflection coefficients, but had difficulty in correlating these with the wave-lengths. However, we spent almost the entire summer in accumulating data regarding these maxima, the reflection coefficients and the corresponding wave-lengths—then it occurred to us that we should test the films before they were cross-ruled. For them we found similar maxima. The phenomenon which we had discovered was not concerned with the length and breadth of the metallic rectangles, but with the thickness of the film and its manner of deposit (voltage, gas pressure, etc.). Since we had not found for light a phenomenon analogous to the resonance in evidence when electric waves are reflected from metallic strips of certain lengths, our experimental results, therefore, pointed to a conclusion at variance with that at which Dr. Nichols had arrived in his Berlin work. However, no time was left in which to pursue the matter further. With the ending of the summer vacation came the breaking up of our comradeship in research. Dr. Nichols went to Columbia, I remained in Dartmouth to take up a larger teaching load.

Perhaps the most important feature in connection with the experiment just considered was the point of view. We had very clearly before us the picture of light as due to an electrical oscillation, the frequency radiated being the frequency of the oscillation. Energy states of atoms and molecules had not been visioned. Frequency of light as due merely to a change of energy, except in the form as proposed by Planck, was unthinkable. In those days we felt that we had to have a mechanism which was responsible for the frequency. What a revolution in our mode of thought as we turn from "explaining" the scattering of light on the classical theory to "explaining" it on the basis of the Raman effect.

But though the domain of physics has vastly increased, though the theoretical viewpoints have greatly altered, the criteria regarding human qualities remain unchanged and the test of the value of a companionship may perhaps best be found by looking back upon it after some years. One recalls the mutual confidence, the constant interchange of views, the common zeal in work, the occasional mingling in play. And always there stands out the keen intuition of Dr. Nichols, his high idealism, his hatred of sham, his loyalty to friends.[7] The four years spent with him were, for me, years of strenuous but congenial labor, years of a memorable scientific comradeship.

[7] For other biographical articles on Dr. Nichols, see P. Fox, Astrophys. J. **61**, 1 (1925); G. F. Hull, Dartmouth Alumni Magazine, June, 1924.

Concerning the A. A. P. T. Book of Demonstration Experiments

MANY A. A. P. T. members have not yet contributed anything to the growing collection of demonstration experiments. Modesty or procrastination doubtless persuades many to keep useful information to themselves. The Editors desire to make the book thoroughly representative, and they are confident that much valuable material is still outstanding. They do not want to prolong the period of preparation unduly, and they ask that you contribute ideas *between now and the end of June*. Lecture experiments in all fields of general physics are welcome, but experiments dealing with aspects of modern physics are particularly needed at present. Information about special technics or materials is always desired. Send contributions to Dr. Richard M. Sutton, Editor, Haverford College, Haverford, Pa.

Present Conceptions of the Metallic State[1]

L. W. Nordheim, *Department of Physics, Purdue University, Lafayette, Indiana*

THE peculiar properties of metals, particularly their high electrical and heat conductivities which occur without transport of matter, suggested at the beginning of this century the conception of a free electron "gas" inside the metal. In this theory, which was due to Drude and Lorentz, some of the atomic electrons were pictured as moving freely in the interstices of the atoms, the energy and momentum of the electrons and atoms being interchanged only in "collision processes." The conduction of electricity corresponded simply to a steady flow of this electron gas as a result of the combined action of an external field and a "friction" due to the collisions, and the thermal conduction corresponded to the transport of heat as in an ordinary gas. With this picture other effects also were explained satisfactorily; for example, according to Richardson, thermionic emission meant that a few electrons had a high kinetic energy, in accordance with Maxwell's distribution law, and were able to overcome the potential of the surface.

But when one tried to determine the properties of this electron gas more accurately, *viz.* the actual number of the "free" electrons, one invariably ran into contradictions. Since the electrons take part in the heat motion, as is shown by the thermal and emission effects, they also should contribute to the specific heat of the metal. Moreover, according to the equipartition law of classical statistics, each electron should have as much energy and hence contribute as much to the specific heat as does an atom. But as the metals show no appreciable deviation from the Dulong-Petit law one had to conclude that the number n of free electrons was only about 1 percent of the number of atoms. On the other hand, the Hall effect, variation of the index of refraction with wavelength and some other phenomena could be accounted for only if n was to be of the same order as the number of atoms. Also the high mobility of the electrons which exists in spite of the very large and rapidly varying field of force in the immediate neighborhood of atoms and ions seemed to be very hard to explain. Although the Drude-Lorentz theory certainly contained an element of truth, it was obvious that something essential had been left out.

As shown by Sommerfeld, Bloch and others, quantum mechanics, making use of the wave nature of the electron and the Pauli exclusion principle, was able to meet this difficulty. Without going into details one can say that the motion of an electron in a crystal lattice resembles more the propagation of an x-ray wave than that of a particle in a field of force. Now an x-ray wave is scattered by a single atom, but when the atoms are regularly distributed as in a crystal the result of their combined influence is simply the propagation of one single wave with modified velocity, or wavelength. From this analogy it is seen that an electron cannot be confined to a certain place at a certain atom but will belong to the crystal as a whole, and in an ideal lattice it could move without any friction. From this point of view, the problem to be solved is not so much the existence of metals and conduction, but rather of insulators and resistance.

To understand this, it is necessary to make use of the Pauli exclusion principle. In the atoms, as is well known, there are different possible energy states for the electrons (specified by certain quantum numbers) and one obtains a complete description of the properties of all atoms, by assuming that not more than two electrons can be in the same energy state. This is the Pauli exclusion principle. Since this principle applies generally to any system where electrons are concerned, it must hold for the crystals as well as for the atoms, and one can ask now what happens to the different electronic states of the atoms as they are brought together to form a solid aggregate. To every energy state in an atom there must correspond a state in the crystal,

[1] For a more detailed account of the present state of the theory of metals, where also references to the original papers can be found, see the summarizing articles of L. Nordheim, in Müller-Pouillet, *Lehrbuch der Physik* (Braunschweig, 1934), vol. IV, pt. 4, chap. 6–9; H. Bethe and A. Sommerfeld, *Handbuch der Physik*, ed. 2 (Berlin, 1934), vol. XXIV, 2; J. C. Slater, Rev. Mod. Phys. **6**, 209 (1934).

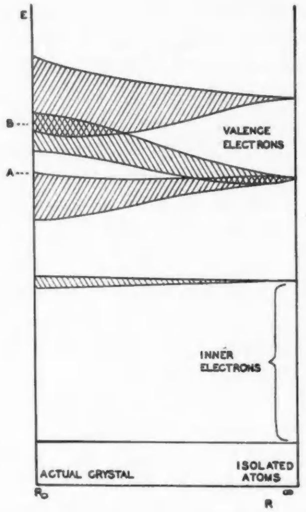


FIG. 1. Energy bands in a crystal as a function of the lattice constant R.

but as each of the latter can contain only two electrons, those of different atoms must go to different states. Thus, *to a definite atomic state there must correspond a manifold of crystal states each of which does not belong to a single atom but to the crystal as a whole.* One can picture this graphically as in Fig. 1, which shows schematically this spreading of the states as a function of R, the distance between the nuclei of the atoms. On the right side, which corresponds to isolated atoms, we have the usual sequence of electronic energy levels in the isolated atom. In going to the left (R decreasing) each single level spreads into a number of crystal states. As long as R is large, this spreading is small for all levels. Moreover, it will remain small for the levels originating from the inner electrons of the atoms, even when R has the values actually observed for the crystal, as these levels will not be influenced much by the presence of neighboring atoms. But for the crystal the spreading will be large for the outer electrons and we get thus a picture of the so called "band or zone structure" of the electronic states in a crystal. There are ranges of energy in which we have practically a continuous distribution of possible electronic states which, as it turns out, correspond to different momenta of the electronic motion in the crystal, while between them there are intervals in which there are no states at all.

These "bands" will be filled with electrons, from the lowest one on, until all electrons have found their places. The electrons that come from the inner closed atomic shells are just sufficient in number to fill the lower "bands" (which incidentally are widely separated). So the most important region will be the one into which the outer valency electrons are going. Due to the fact that the actual lattice constants are of the same order as the atomic dimensions (which means that the charge distribution due to the valence electrons of the different atoms overlap to an appreciable extent) the spreading for these states will be considerable. This evidently has to be the case as only then will the atoms show a considerable interaction; that is, exhibit the large cohesive forces known experimentally to exist between them. Now if the spreading is wide and the atomic levels are near together, as it is for the outer electrons, the corresponding bands may even overlap (see left upper part of Fig. 1), so that one has practically a continuum of energy states; in this case, of course, the coordination of crystal and atomic levels is not unambiguous. It may happen that the limiting level E_0 between filled and empty states is situated either at the upper end of an allowed band (point A, Fig. 1), or inside a band, or even in a region where several zones overlap (B, Fig. 1).

This gives a natural explanation of the difference between insulators and metals. A completely filled band will not contribute to conductivity at all; in order that an electron may be accelerated there must be free places with higher energy available in its neighborhood, which is not the case if all places in a band are filled up. Therefore, it is possible to disregard all the states in complete bands for the study of conductivity. What matters for conduction is not the total number of electrons but only the number of populated levels in those uppermost bands that are not quite filled.

It actually is possible to discuss to a certain extent when case A or B is to be expected. For monovalent substances such as the alkalis and the noble metals copper, silver and gold, the valency electron (here one from each atom) can fill only half a crystal zone. They are for this

reason the best conductors. For the divalent elements (alkaline earths) on the other hand, we have to conclude from the fact that they are metals, that the zones corresponding to the possible states of the valency electrons overlap already, since otherwise they would be insulators. As the extent of this overlapping probably is not very great the effective number of conduction electrons will be smaller than in the case of the monovalent elements and they are therefore poorer conductors. This situation becomes more pronounced when one passes to the transition metals, like bismuth and certain alloys. Here one can show that the zone structure is such that there appear only bands which are nearly filled or nearly empty and from this the different anomalous properties of these substances can be deduced. These metals already show a transition to pure valency binding such as occurs in diamond. As can be shown, the possibility of drawing valency bonds between the different atoms in the lattice corresponds in this case to a division of the electronic levels into entirely filled bands and entirely empty ones (case A). It is in this way possible to correlate a great number of properties of many elements with a definite picture of the degree to which the upper bands are filled, which in turn depends on the valence number and lattice structure.

So far the problem has been treated as if the limits between filled and empty states were absolutely sharp. This actually will be the case at low temperatures when there is no thermal energy available to excite the electrons and always will be true for insulators, where the gap between filled and empty states is large. But for metals at higher temperatures a continuous transition from filled to empty states will take place. It is clearly evident and can be deduced rigorously by the Fermi statistics, that this will affect chiefly the electrons situated in a region of width kT from the critical energy E_0 (k being the Boltzmann constant and T the absolute temperature); the number affected will therefore only be a small fraction of all the electrons. Only these will actually be excited thermally and their contribution to the specific heat will be very small, so small that the difficulty of the classical theory disappears completely.

It is now possible to understand the mechanism of the electric resistance. As was said before, the conduction electrons in a metal (the ones in the uppermost, only partly filled band) could be accelerated freely by an external field if the lattice were really perfect. This means that resistance must be caused by some irregularity or deviation from the perfect state, and vice versa, that every irregularity must produce a resistance. One type of disorder will always be present; namely, the one due to the heat motion of the atomic ions themselves. The ions are never completely at rest but oscillate around their equilibrium position. The resistance which these vibrations offer to the motion of the electrons will be roughly proportional to the energy of heat motion; that is, to kT. This is certainly correct for high temperatures. At lower temperatures, however, one knows that the heat vibrations "freeze in," which means they die down quicker than if proportional to T; therefore the resistance will also decrease more rapidly; in fact, it comes out proportional to T^5, in agreement with experiment.

Besides this thermal disorder, fixed irregularities may be present in the lattice, such as are produced by impurities, alloying and deformations. They give rise to a scattering of electrons which will be independent of T. Therefore, to the regular resistance there must be added a constant term which is practically independent of temperature and which will vary from sample to sample according to its degree of perfection. This is the interpretation of the well known Matthiessen rule.

The most interesting effect of this kind is furnished by the solid solutions of one metal in another one; that is, when a number of atoms in the lattice of a basic substance are replaced by atoms of a different sort. In spite of the fact that the lattice structure is preserved, one observes in such cases an enormous increase of resistance, a fact which seemed to be inexplicable in the older theory. But now we see the reason at once. A foreign atom has a different potential from the original one, and acts therefore as a scattering center for the electron waves, even when in the correct lattice position.

The additional resistance (independent of T) as a function of the atomic concentration will show a behavior as in Fig. 2. It will increase

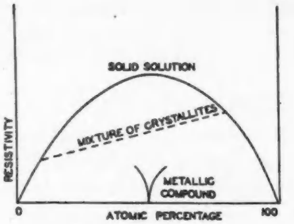


FIG. 2. Effect of composition on the additional resistance in alloys.

linearly for small concentrations of the foreign atoms; this represents independent superposition of scattering due to different centers at wide separation. But for higher concentrations the increase will be slower until for a 50-percent mixture a maximum is reached. For still higher concentrations, when there is an exchange of the role of "basic" substance and "impurity," we get a decrease which would be symmetrical under ideal conditions; but a number of secondary effects will tend to distort the curve. This holds only for an ideal solid solution. For a mixture of crystallites one has instead a linear connection (broken line in Fig. 2) between the points that correspond to the maximum concentration of foreign atoms which can be built in as solid solution. This additional resistance will not be found, on the other hand, for so called metallic compounds with a definite rational ratio of the number of different atoms. Here again perfect order is possible and such compounds show therefore a behavior similar to that of pure metals. All these facts, well known to metallurgists, find their natural explanation in the conceptions of the present theory.

Although all the results reported so far can be derived qualitatively from considerations of the behavior of wave functions in a crystal, quantitatively all attempts were unsuccessful for a long time. Naturally, for a first approximation one started with the limiting cases of either nearly free or very strongly bound electrons. Both proved to be insufficient. The real wave functions are apparently just an intermediate case. Near the centers of the ions they certainly must resemble those for the free atom. In the interstices, however, the free electron picture seems to be the more accurate. Recently a satisfactory and ingenious method of approaching the problem has been given by Wigner and Seitz and by Slater and his collaborators.

If one imagines the whole crystal built up out of many-sided cells around each ion, obtained by constructing all surfaces which bisect orthogonally all lines connecting neighboring ions, then by symmetry considerations the whole wave function in the crystal can be found if it is known for one cell. As every cell is very nearly spherically symmetrical and electrically neutral, the potential inside is practically that due to the ion at its center. The difference from the case of isolated atoms consists then only in the different boundary conditions. For free atoms the wave function of the valence electron must vanish at large distances, whereas in the crystal one has instead the condition that it must join smoothly the functions in adjacent cells. In this way many properties, such as the total cohesion energy for the alkalis, and the actual lattice constants, have been worked out in satisfactory agreement with experiment. So it is to be hoped that in the near future many problems of the metallic state can be treated quantitatively. As shown clearly by all examples treated hitherto, the new boundary condition of continuity alone enforces a "flattening out" of the wave functions near the boundaries of the cells, so that this method gives automatically a kind of hybridization of the qualities of electronic wave functions as in atoms and of plane waves, corresponding to free electrons.

Due to the latter, the propagation properties of the electron waves are found to be very nearly the same as for free electrons thus giving a more solid background for the results which have been described. In its most refined form, then, the wave theory of the metallic state leads back to the "free electron" picture just to the extent that is essential for the understanding of the typical properties of metals.

Reprints of Survey Articles for Class Use

REPRINTS of the above article by Dr. L. W. Nordheim on "Present Conceptions of the Metallic State" may be obtained at cost from the Editor. The cost for 6 reprints is 30 cts. postpaid.

Acceleration Calculations from Spark-Recorded Data

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IT has been pointed out[1] that the development of spark-recording devices operated by a.c. synchronous motors has made possible the precise measurement of accelerations in the general laboratory. The general laboratory has gained a further advantage from the fact that a single spark-recording device can be easily adapted for use with several different types of apparatus: free-fall, Atwood's machine, Fletcher's apparatus, etc.

The spark-recording device is a nearly foolproof precision instrument which makes the observations itself. Only very moderate ability is required to read off the data obtained by the machine with as much accuracy as is desirable. The readings obtained are so good, particularly with the Behr free-fall apparatus, that they merit the best treatment. Special methods of treatment are to be found in the manufacturer's literature and in this periodical.[1] Critical examination of these treatments shows that while they generally use all of the readings they do not weight these readings properly. Probably the correct treatment has not been used because of the time required and because the students in the general courses could not be expected to understand it.

After many experiments with a Behr free-fall apparatus, the author has found that most of the error in the observed value of the acceleration can be ascribed to the random distribution of the spark holes in the paper about the most probable position of the bob at the given instant of time.[2] This is probably due to slight oscillations in the bob's axis while falling and to the failure of the spark to take the shortest path from the bob in puncturing the paper. Errors of this type obviously are random and therefore should be treated by the method of least squares.

Teachers will object to the method of least squares for use in the elementary laboratory because it is generally tedious to apply and difficult to explain to beginners. However, since the observations are taken at equal intervals of time, a general formula can be obtained that reduces the calculation of the acceleration to a mere substitution in a simple formula which is given below. Moreover, *the author has found it much simpler to explain to his students why it is desirable to use the least squares formula than to explain the reasons for any of the approximate methods*, which have little theoretical background. This has the added pedagogical advantage of showing the student that there is a method of treating data which he later may find desirable to investigate.

In many of the suggested methods of treatment, the distances between the successive holes in the recording tape are measured. These distances are recorded and treated as observations upon the average speeds of the bob during the respective intervals. It is better practice, and just as easy, to place the recording tape on a flat table, lay a long ruler beside it and record the *positions* of the holes in the tape.[3] These positions, S_1, S_2, S_3, etc., recorded by the instrument, should be treated as the true observations. The most probable value of the acceleration is obtained by substituting these S's directly in the proper formula.

The following are the least squares formulas for the acceleration from 6, 10 and 14 observations, respectively, where T represents the time interval between sparks:

$$a=\{5(S_1+S_6)-(S_2+S_5)-4(S_3+S_4)\}/28T^2,$$

$$\begin{aligned} a=\{6(S_1+S_{10})+2(S_2+S_9)-(S_3+S_8) \\ -3(S_4+S_7)-4(S_5+S_6)\}/132T^2, \end{aligned} \quad (1)$$

$$\begin{aligned} a=\{13(S_1+S_{14})+7(S_2+S_{13})+2(S_3+S_{12}) \\ -2(S_4+S_{11})-5(S_5+S_{10})-7(S_6+S_9) \\ -8(S_7+S_8)\}/728T^2. \end{aligned}$$

[1] R. L. Edwards, Am. Phys. Teacher **1**, 6 (1933).

[2] Errors in the calculated acceleration may occur due to deviations in the a. c. frequency from its nominal value. The frequency is apparently constant during the making of one record, otherwise the deviations of the positions of the spark holes from their theoretical values would tend to increase with speed. No such tendency has been observed by the author.

[3] The position of the zero on the ruler is of no importance, since the coefficients of the S's in the formula always add up to zero. Thus, if all of the S's are increased or decreased by a constant, the calculated value of the acceleration will be unchanged.

The formula for any number of readings n can be obtained from the general expression:[4]

$$a=\frac{60\sum_{r=1}^{r=n}\{[(n+1)(n+2)-6(n+1)r+6r^2]S_r\}}{T^2(n-2)(n-1)n(n+1)(n+2)}. \quad (2)$$

The student should use these formulas only after he has obtained an approximate value of the acceleration in some simple manner. The simple calculation should aid the student in forming his physical picture of motion with constant acceleration. It is our practice to have students calculate and tabulate columns of "readings," "average speeds in each interval" (from the first differences) and "accelerations" (from second differences). The figures in the last column are nearly constant if the data are good, but their arithmetical mean is affected only by the first two and the last two readings. Therefore, one cannot expect good results from such a procedure. How the least squares treatment improves the result can be seen from the typical results given in Table I. It will be noticed that the method of least squares gives the most consistent results. The educational value of the increased accuracy in the results obtained is well worth the little extra time required for the calculations.

TABLE I. *Accelerations in a Behr free-fall apparatus as calculated from data taken independently by two observers from two recording tapes, twelve observations on each tape.*

Tape	Observer	Arith. Mean	Special Method[1]	Least Squares
1	1	984.0	976.6	977.6
	2	985.5	975.9	978.2
2	1	987.0	975.4	978.1
	2	993.8	979.2	978.8

[4] Assume that the motion of the body follows the law

$$S=S_0+v_0t+\tfrac{1}{2}at^2.$$

The observation equations are

$$S_1=S_0+v_0T+\tfrac{1}{2}aT^2,$$
$$S_2=S_0+v_02T+\tfrac{1}{2}a4T^2,$$
$$\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot$$
$$S_n=S_0+v_0nT+\tfrac{1}{2}an^2T^2.$$

If we let $v_0T=B$ and $aT^2/2=A$, normal equations for the unknown constants A, B, and S_0 can be formed in the usual way. The normal equations are

$$S_0n+B\Sigma r+A\Sigma r^2=\Sigma S_r,$$
$$S_0\Sigma r+B\Sigma r^2+A\Sigma r^3=\Sigma rS_r,$$
$$S_0\Sigma r^2+B\Sigma r^3+A\Sigma r^4=\Sigma r^2S_r.$$

In the summations r takes all values from 1 to n. The values of Σr, Σr^2, Σr^3 and Σr^4 are known [H. B. Dwight, *Tables of Integrals and other Mathematical Data* (Macmillan, 1934), p. 6]. Solution of these simultaneous equations for A gives Eq. (2). This is the least squares solution for any polynomial of the second order. It has just come to the author's attention that R. T. Birge and J. D. Shea [Univ. of Calif. Pub. in Math. **2**, No. 5, 67–118 (1927)] have published least squares solutions in different form for polynomials up to the fifth order.

The New Physics and the Undergraduate

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One of my assistants has recently made an examination of some 300 college and university catalogs for the purpose of determining what opportunities are offered to the non-technical undergraduate who wishes to acquire some moderate and reasonably sound information concerning the new physics—the only branch of physics that he encounters in his reading of current literature. The answer is that, so far as the information gleaned from these catalogs may be relied upon, there are only two or three institutions in the entire list where it has been possible for such a student to take a course in modern physics without having had previously either a year of general physics or a year of mathematics, or both. Of course, a college catalog is notoriously tricky reading, and it may well be that in a few cases our interpretation has been wrong. The general situation is clear, however. Whatever contact the undergraduate whose major interest lies outside of physics or chemistry is to have with modern physics must come as a part of a course in general physics. How much is this likely to be? Perhaps as good an estimate as any may be made by considering the place allotted to this subject by the Committee on Tests of the American Association of Physics Teachers. Twenty-five questions out of a total

of 225 are on this subject. This evaluates the time allotment as equivalent to between three and four weeks out of the college year. That is, we make provision for less than a month's study of this part of physics, and that only if the student spends the remainder of the year upon the older parts of the field. Perhaps this is as it should be, but it is surely proper that those who represent any growing branch of knowledge should from time to time question the established pedagogy of their field, and that this questioning should extend to the content of courses and organization of materials as well as to the minutiae of the classroom.

What courses in physics are open to students? A study of catalogs indicates, as might be expected, that the colleges may be divided into four groups so far as their offerings in physics are concerned:

1. A few four-year institutions calling themselves colleges offer no physics at all. These are almost wholly among the smallest and weakest of the denominational institutions.
2. Another group, rather considerable in number, offers a single course in general physics, usually given by an instructor who doubles in mathematics or chemistry.
3. Most institutions with enrollments of 400 to 1000 students have a separate department of physics with one or more qualified men devoting their entire time to it. Here the normal offering is general physics followed by a half-year each of mechanics, heat, electricity, sound and light. In a considerable number of these institutions an elective in modern physics is offered in the junior or senior year for students who have had a year of general physics and one or two years of college mathematics. In a smaller number modern physics appears to be the normal second-year course for those expecting to major in physics.
4. In the universities and larger colleges the normal offerings are essentially as in the stronger small colleges with the added possibility that the undergraduate student who has the necessary ability may make his choice from a considerably greater number of courses.

So far as modern physics is concerned it appears to be something reserved for the elect—well guarded by prerequisites and open only to those who expect it to have some fairly definite relation to their life work. The non-science major, if he elects to study physics at all, must begin with a course in general physics. In the smaller institutions this will be the same course as that for the scientific group. In larger institutions two variants of the general physics course often appear:

The first is a special course frequently designated as elementary physics, for those who do not present high school physics as an entrance subject. It is likely to be quite essentially the general physics, reduced in difficulty to whatever extent the instructor may have found desirable; it treats essentially the same topics, in the same order, and with the same relative emphasis, but with the most difficult points omitted. Perhaps it might be described as "dehorned physics."

The second is frankly a feminized course under the name of Household Physics. If one may judge by the textbooks, it is a course in general physics, of high school range so far as rigor of treatment is concerned, in which doorbells, sewing machines, egg beaters, and cook stoves supply the illustrative material.

Please do not misunderstand me. I have no disposition to be critical of such courses. The point I am trying to make is that we, as teachers of physics, have shown a striking lack of imagination in the construction of our offerings for the nontechnical student. With some few exceptions, we have envisaged a reduction of the traditional course in general physics as the only solution of the problem: What shall we offer the nontechnical student?

With this in mind, it may be well to inquire into the origins of the general course. By what right has it come to dominate the field? Perhaps the first thing to be said of the traditional course is that it is traditional. You and I and generations of physicists before us were nurtured upon it. My own first experience with the subject dates almost exactly from the beginning of the modern period. The text I used as an undergraduate was one familiar to all the older readers—Carhart's *University Physics*. In content, arrangement, and method of treatment it lacked only an additional two or three chapters upon electrons, radio, etc. to be fairly comparable with texts in use today—this in spite of the frequently quoted estimate that more than half of all that we know of physics has been discovered since that time. But the tradition of the general course is older than this. The generation preceding took its first look at physics mostly through Ganot's *Physics*, and this was the model for many later books. I used to have a

copy of a two-volume work by Biot and a collaborator, whose name I have forgotten, which bore the date of 1819 and in which the traditional order and treatment was already well developed, although electric currents, of necessity, occupied a position somewhat like that of modern physics in a text of, say, 1905.

Perhaps you will say that an order of development which has maintained itself for more than a century must have something to recommend it. If so, I agree with you. There can, I think, be no serious question as to the soundness of the logic that introduces the study of physics with the subject of mechanics. This arises from the predominance of mechanical experiences. Physics is the study of things and their behavior as manifested through our sense organs or through these same organs extended in range by such aids as eyeglasses, telescopes, microscopes, electroscopes, Geiger counters, and cloud chambers. Of our simpler and more direct experiences the overwhelming majority are mechanical in nature. As a result, we have long been accustomed to explain other phenomena in terms of mechanical models. One may recall that Huygens in his treatise on light speaks of "the true philosophy where one believes all natural phenomena to be mechanical effects"; and adds, ". . . in my opinion, we must admit this, or else give up all hope of ever understanding anything in physics."

There is, however, more than tradition behind this persistence of the old order. Physics has been taught to a large extent as a service subject rather than for its own values. This has been and will continue to be inevitable. A great part of all engineering is simply applied physics. The engineering schools have been the strongholds of physics teaching, and the physics taught in such institutions has properly been dictated by what have been assumed to be the requisites for satisfactory introduction to the work of the later years. Even in the Arts colleges the courses in general physics have been dominated by the pre-engineering requirement. Upon the whole, it seems that the traditional course has been well adapted to this service end. It does not follow, however, that the same course or any emasculated copy of it will be well adapted to the needs of the premedical student or the non-scientific man or woman. Perhaps physics is worth teaching for reasons other than its pre-engineering values, and perhaps also the securing of these ends may demand a quite different selection, ordering, and treatment of material.

There is still another influence which has assisted in molding the present-day course. The traditional treatment lends itself well to our time divisions of terms and semesters. Mechanics and heat, sound and light, electricity and magnetism are fragments which may be taken as units, and we have come to isolate them so completely that the student may begin anywhere in the cycle. Under our lunch-counter system of education this fragmentization has its values, and, as a practical matter, probably must be recognized in any treatment. All in all, I think that when the course in general physics is viewed biologically—from the standpoint of evolution and environment—one must admit, at least, that it possesses survival values. It is what it is because that kind of a course has proven good for the embryo physicist and pre-engineering student. Its development is logical and satisfying to a large part of the group for which it has been designed.

But one may admit the soundness of the logic and yet question the pedagogical rightness of the traditional order, or perhaps even of the course in general physics itself for the non-science student. I suspect that logic and pedagogy have little in common. Perhaps a sound pedagogical order ought to be based upon interest and curiosity and current nontechnical literature rather than upon what appears to the expert as a logical progression. Perhaps we should ask as to the possible intellectual values of physics, and, if we conclude that some knowledge of physics is a useful tool for understanding the way in which modern people think, inquire if the traditional courses are serving this end.

There is no use attempting to evade the fact that physics has a bad name among students in both high school and college. Too often the student of general physics shares the opinion of that friend of my youth who inscribed his

copy of a text, which I refrain from identifying, with the doggerel lines:

> Should there be another flood
> For refuge hither fly;
> Though all around be wet,
> This book will still be dry.

There may be profit in attempting to learn the causes of this bad repute, but perhaps one first should make some qualifications and introduce some evidence.

I have already pointed out that one need not be greatly concerned about the student whose natural inclinations lead him into the physical sciences. He will take care of himself, and for him our present texts and general courses, as judged by results, provide a reasonably satisfactory introduction, and later courses in modern physics are available. It is of physics for the non-science major that I speak, and I may now propose openly the question at which I have so far merely hinted: *Is it possible that the subject matter of general physics has grown to such an extent that a course which attempts to treat all parts of the subject within the limits of six or eight semester hours is quite an impossible undertaking for any except those whose abilities and training lie in this field?*[1]

What can we learn from the reactions of students? Perhaps we may fairly well let the women represent the non-science group. If so, some results of a survey recently made by Professor Daffin of Mary Baldwin College, in which returns from 33 standard women's colleges were studied, are enlightening. These returns show that 5 percent of all the women students took a first course in physics; 9 percent, a first course in chemistry; and nearly 16 percent, a first course in biology. That is, among the sciences physics ranked, a bad third, the number of elections being approximately in the order of 1 for physics, 2 for chemistry, and 3 for biology. As for the major students in the several sciences in these same institutions, these ratios were 1 in physics, 6 in chemistry, and 10 in biology. So far as they may be regarded as typical, these figures indicate with disconcerting clearness the insignificant part that physics plays in nontechnical education. Still worse, they indicate that the first course in physics does not succeed in capturing student interest to an extent comparable with the corresponding courses in chemistry and biology. Of course, there are doubtless additional factors, undisclosed by Professor Daffin's report, that may account partly for the differences in the several fields. Perhaps the vocational opportunities for women for which the study of chemistry or biology furnishes preparation are greater than those for which the study of physics is necessary. Yet, I believe that these figures represent a fairly general situation which we cannot deny, and which ought to give us much concern. Quite generally the nontechnical student avoids physics, and those who do come in contact with the subject seem, for the most part, to discontinue it as quickly as possible. A sentence from Professor Daffin's report is worth quoting as an ideal: "Physics should be made sufficiently attractive to women in such institutions that they may recognize the same enjoyment from the pursuit of the knowledge of physics as of any other subject."

When one attempts to analyze the reasons for this avoidance of physics, he encounters difficulty. There is, of course, no authoritative source of information other than those students who do not take physics, and, quite naturally, the physics teacher is not in a position to secure much real information from this group. Perhaps, also, the students who do not take physics have, in general, no specific and recognizable reason for this negative choice. It simply does not attract them. If we think it desirable that some contact with physics should be a part of the education of more than five percent of the nontechnical college graduates, we must recognize this fact and proceed accordingly. In the past we have tried to solve the problem by multiplying pictorial material and by reducing rigor of treatment. I assume that Professor Daffin's findings may be accepted as evidence that this procedure has had a very limited success.

I have recently asked several students who have had experience in the other sciences to

[1] This same question was raised by G. W. Stewart, Am. Phys. Teacher **1**, 65 (1933).

compare the introductory courses, as to the reasons for their appeal to non-science students. A digest of their replies runs something as follows:

Chemistry and biology have more obvious applications to life, to the planning of menus and the care of babies.

Chemistry in particular is more colorful. The laboratory work is more attractive because something unexpected is likely to happen at any instant.

Most students have a greater feeling that they have understood and, to some degree, mastered the materials and theories of chemistry and biology than is true in physics. In chemistry everything centers about the atomic theory, and the same procedures repeat themselves until they become familiar, whereas in physics one is continually going to something new that seems to bear little relation to what has gone before. There is less feeling of accomplishment.

The first of these reasons is, of course, a feminine reaction, and, since it is probably true, there seems little that the physicist can do about it. The second is perhaps inherent in the nature of the subjects, but contains also some kernels of suggestion. Do enough things happen in our laboratories? Of course, laboratory work in general chemistry is qualitative, for the most part, whereas work in the physics laboratory is mostly quantitative. Is this as it should be?

It is, however, to the third reason that I wish to direct attention. It will be observed to bear upon the question raised some time ago, of whether the field of general physics has become too extensive for a one-year introductory course? It also contains a very keen and fundamental criticism: because the course is too extensive it is superficial and the student leaves it with no sense of useful mastery. If this is a real formulation of an important reason for the bad repute into which physics has fallen, it appears that we may have been seeking a remedy in the wrong direction when we have offered non-science students easy courses in general physics. What we should do is quite the opposite. Instead of trying to cover the whole field, we should select certain topics, each of which has an appeal to some group, and attempt to give enough understanding of that topic so that the student will leave the course with a feeling of accomplishment. As an illustration of what may be done in this way, I may cite the experiment of Professor G. W. Stewart in teaching sound to students of music and psychology who are quite innocent of any previous training in either physics or mathematics. Doubtless other groups might arise, having similar vocational interests, but there is at present one field, that of modern physics, which seems to offer a particularly attractive field for experimentation.

So far as my information goes, there is only one man who has ventured the experiment, and his success was notable. Several years ago Professor A. B. Carr of Simpson College offered such a course which carried one semester hour of credit. It was elected by 63 students and four of these became sufficiently interested to take additional work in the department. I know little about either the content or the method of this course. Considering the time allotment, the work may have been open to many criticisms upon the ground of superficiality, and it may not have done much for the inculcation of those habits of precision of statement, rigorously exact thinking, and the use of scientific methodology which we like to look upon as by-products of the study of physics. But two things it did do. It offered a considerable number of students an opportunity to learn something about a subject in which they were interested, and it created in some of them a desire to know more of the whole field. I submit to you that these are desirable ends which our usual introductory courses do not always attain.

Here is a problem in organizing material that offers unlimited opportunity for an experiment of real significance in teaching. If a dozen people during the next year were to try giving a course in modern physics, of not less than three semester hours, open only to non-science students, and were to estimate carefully and compare their results, some one might then prepare a really illuminating paper upon the "Undergraduate and Modern Physics."

Application of an Electrical Timing Device to Certain Mechanics Experiments

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THIS article describes some new mechanics experiments which have been introduced into the first year physics course at Massachusetts Institute of Technology. The experiments consist of analyses of certain types of straight line motions of a body by means of a record of its position at consecutive instants of time. The method used for obtaining the record has been described by Behr and Reynolds.[1] Briefly, it is as follows. Parallel to the direction of the motion of the body is mounted a bare wire. The output terminals of a spark coil are connected to the body and the wire, and an electrical-timing device activates the coil at regularly spaced instants. Between the wire and the body is stretched a strip of stylograph paper and the perforations produced on it by the spark jumping between the body and wire give the position of the body at these same instants.

1. The electrical timing device

The circuit of the electrical timing device (Fig. 1) is identical with that of an automobile ignition system. The breaker points P are operated at a fixed frequency so that if the switch S is closed the primary circuit is broken at regular intervals, thus producing an intermittent e.m.f. in the secondary.

It was desired to run eight sets of coils simultaneously in the laboratory, but it was found that if more than one coil was used with the same set of points the results were not satisfactory. Therefore a unit was constructed containing eight sets of Ford Model "A" point assemblies, with eight cams mounted on a common 3/8-in. steel shaft driven by a 1/5-h.p. synchronous motor. The cams were made of 1/2-in. square steel with three corners rounded off thus giving 30 sparks/sec. at a motor speed of 1800 r.p.m. Ford "V8" coils were found to be the most satisfactory though it is desirable to use an 0.5-μf condenser across the points in addition to the 0.25-μf condenser contained in the coil. A

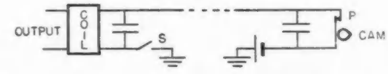

FIG. 1. Diagram of circuit for timing device.

3/4-in. spark at the output can be depended upon if the voltage at the primary terminals is 5–6 volts. The motor and point assembly were mounted on a piece of channel iron and enclosed in a soundproof box lined with 1 in. of felt. This unit was mounted at a central point in the laboratory and leads carried out to the coils, which can be placed wherever desired. The shock hazard turned out to be negligible and there were no complaints in a class of 500 students. The cost of materials in the motor, points, and cam units was approximately $50.

2. Falling body apparatus

Electrical timers, similar to the one described, have been used previously to investigate the motion of a falling body.[2] A weight falls between two No. 22 bare copper wires. Between one wire and the weight is stretched a piece of red stylograph paper which is coated with a whitish layer of powdered paraffin. When the output of the spark coil is applied across the two wires, a spark jumps every thirtieth of a second from wire to wire by way of the rim of the weight and melts a readily detected spot about 1 mm in diameter on the paper.

The wires, paper, and mechanism for releasing the weight are mounted on the face of a vertical support consisting of a wooden "two by four" about 6 ft. long. Fig. 2 shows the assembly at the top of the support. The weight J is made of a 4-in. section of 1/2-in. brass rod with a circular rim 1.5 in. in diameter of 1/4-in. brass plate. It is supported by a hook H made of 0.032-in. piano wire. If the hook is tight it will support the weight on a smooth thread B; otherwise a knot in the end of the thread gives a secure purchase. The spool of thread A is held by friction but may be rotated by hand to raise or lower the weight.

[1] Behr and Reynolds, J. O. S. A. and R. S. I. **13**, 216 (1926); see also the catalogs of the Central Scientific Co. and the Welch Scientific Co.

[2] The Central Scientific Co. catalog refers to a similar apparatus described in the manual of Prof. C. R. Fountain.

To prevent the weight from swinging due to air currents or vibrations, the paint brush I is allowed to rest against it lightly. The position of the weight with respect to the high-voltage wires can be adjusted by moving the plate E, which is fastened on the bracket by means of a bolt and washers, the hole in E being somewhat larger than the bolt; this adjustment is made only once unless the size of the weight or position of the wires is changed. Above the plate E the thread presses lightly against a section of 0.012 or 0.006-in. chromel resistance wire D, clamped by set screws in two 1/4-in. brass rods C. To release the weight, the thread is burned by passing a heating current from a toy transformer through this wire.

One of the high-voltage wires is placed behind the weight and the other to the left. The rear wire N is held clear from the support by placing it in a groove in a 3/16-in. brass rod M stapled onto the support, an arrangement which allows the wire to be shifted sidewise by sliding the rod through the staples. The ends of this wire are secured by running them through holes on the support and fastening them on the back. It is found convenient to fasten a spring onto one end in order to facilitate taking up any slack. The side wire G is not adjustable and is fastened

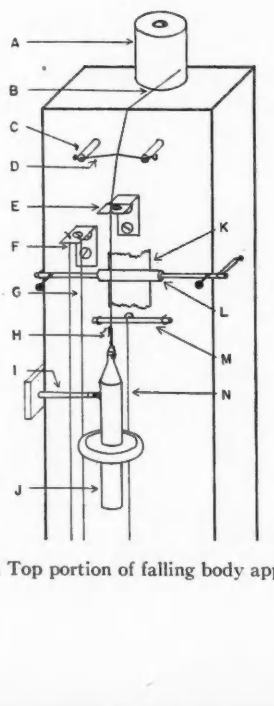

FIG. 2. Top portion of falling body apparatus.

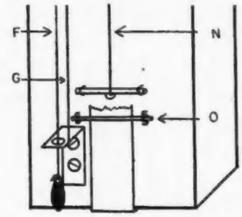

FIG. 3. Front view of bottom portion of apparatus.

to a bracket, as shown. The string F attached to the same bracket is part of a plumb line.

Part of the paper strip and the top paper clamps are shown at K and L. The clamp L is made of 1/4-in. brass rod with holes bored for nails, as shown. A piece of rubber tubing slipped over the rod gives good traction on the paper. Rubber bands furnish the force.

The bottom assembly is shown in Figs. 3 and 4. If the upper and lower brackets have the same dimensions, the apparatus can be made vertical by adjusting it so that the plumb line F is centered in the hole. The roll of stylograph paper is mounted on the back of the support (Fig. 4) and is fed up under the 1/8-in. brass rod O (Fig. 3) which keeps it from bulging out in front of the apparatus. Due to the natural curl, the paper tends to lie flat against the back wire. Fig. 4 shows the device used for catching the weight. It is a felt-lined wooden box in which is mounted a slanting board. After bouncing from the felt-covered board to the end of the box, the weight will not bounce out and dent the rim.

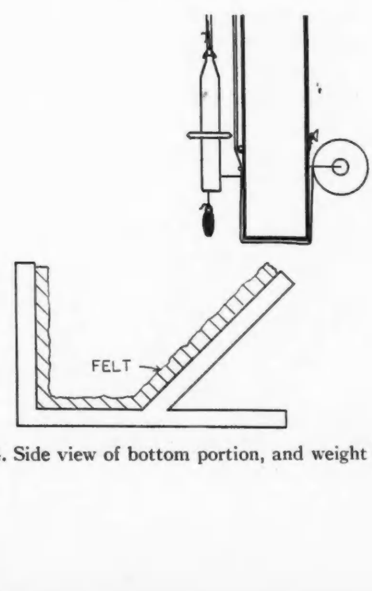

FIG. 4. Side view of bottom portion, and weight receiver.

To insure both the sparking and thread-burning circuits being completed simultaneously, a double-pole single-throw snap switch was used. Two minor points in construction should be mentioned. The sparking wires should be so separated that there is no chance of sparks jumping between them after the weight has fallen. The 1.5-in. rim on the weight gave a satisfactory spacing. Enough space should be allowed at the end assemblies to insure insulating spacing between the wires.

Desirable features of this apparatus. (1) The materials for construction are readily obtained and inexpensive. The machine work does not require great skill. Stylograph paper (1-in. width) costs less than half a cent per run. Except for the leveling bases, the cost of the materials for 8 sets of apparatus and the timer was approximately $100. (2) The only parts that are likely to be damaged are the two vertical wires and the resistance wire. These may be tightened easily, or replaced, as occasion demands. Wires have the advantage over rigid members in that they cannot become permanently distorted. Warping of the wooden support introduces no difficulty unless it presses against the back wire; in this case it is easy to straighten it by guy wires. (3) It is not hard to adjust the apparatus so that the space between the back wire and weight is less than 2 mm. This insures the spots being accurate to within less than 2 mm, an accuracy sufficient to measure g to 1 percent by considering only two intervals on the paper tape separated by half a second of fall.

3. Sliding friction

A natural application of the electrical timer is to the case of sliding friction. A brass weight B (Fig. 5) slides down a 3/4-in. square brass tube A which is grounded and connected to one side of the spark coil. The high voltage wire and stylograph paper are supported by fiber board strips C screwed to the bottom of the tube. The known slope of A and the acceleration, obtained from the strip, are used to calculate the coefficient of friction.

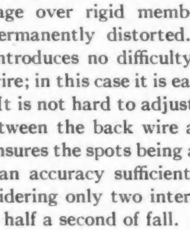

FIG. 5. Apparatus for studying sliding friction.

4. Newton's second law of motion

Fig. 6 is an apparatus designed to test Newton's second law of motion for the case of straight line motion and for forces that do not change rapidly with the displacement. A T-shaped mass m is suspended by three wires which allow it to move along the arc of a very large circle. The acceleration is measured over such a short arc that the vertical motion can be disregarded. The accelerating force is furnished by a spring S, whose mass is negligible compared to m. The student detaches m from the spring balance B, pulls it back, and then releases it after closing the switch which applies the output of the spark coil to the mass and a copper plate. The series of sparks from P to the plate leaves a record of the motion on the paper. One of the spots near the center of the strip is singled out for consideration and the force which acted on the mass when it was at this spot is measured on the balance B, the lever L being raised or lowered until P stands directly above the chosen spot.

To compute the acceleration, let the chosen spot be called c and the spots which preceded it and followed it by 0.1 sec (3 times the timer's natural interval) be called b and d, respectively. If the instants at which these spots were formed are taken as 0.0, 0.1, 0.2 sec, then the speed at 0.05 sec was $\overline{bc}/0.1$ cm·sec^{-1}; that is, the average speed from b to c is a good approximation to the speed at the middle time between b and c. The error resulting from this assumption is much less than 1 percent. Similarly the speed at 0.15 sec was $\overline{cd}/0.1$ cm·sec^{-1}. Hence, the acceleration at 0.1 sec is given by $(\overline{cd}-\overline{bc})/(0.1)^2=100(\overline{cd}-\overline{bc})$ cm·sec^{-2}.

Three students were assigned to each apparatus: the first made three runs with three different speeds obtained by releasing m from different positions; the second proceeded similarly, but

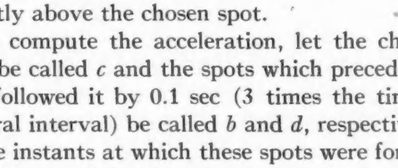

FIG. 6. Method of testing Newton's second law.

changed the spring tension before starting, to obtain a different force; the third changed the value of m and proceeded as before. Thus cases differing in the values of mass, force, and speed were obtained.

Mechanically the greatest difficulty encountered was in keeping a sufficiently small sparking distance between the point and the plate over the whole distance travelled. For this purpose the plate was bent in an arc. Preliminary experiments with a flat plate and a point mounted on a drag which rests lightly against the paper have been satisfactory.[3]

Pedagogically the experiment has several characteristics to recommend it. It does not introduce possible confusion between gravitational and inertial mass, and, for accelerations such as can be measured with the timer, frictional forces are negligible. The students measured the forces in ounces and m and a in c.g.s. units, and computed ma/F, the number of dynes per ounce of force. The average total spread of this value in a given group of three students was 5 percent and the mean value obtained by a group differed from the correct value by 1.5 percent on the average. The use of an arbitrary unit of force such as the ounce has a definite pedagogical advantage in that it demonstrates the proportionality rather than the necessary equality of F and ma. The gram of force seems unsuitable since it involves both gravitational and inertial mass. Possibly a spring balance actually calibrated in dynes would be advantageous.

5. Simple harmonic motion

Another application of the timer is to the case of simple harmonic motion. The spring suspension in Fig. 7 is insulated and connected to the high-voltage side of the induction coil. The other wire is grounded. When the bob is caused to oscillate vertically, the spark jumps from the rim of the bob to the wire and leaves a record of the motion on the paper. Since the bob continues over the same path several times, it is necessary to have some method of distinguishing the various up and down spots from one another. This is accomplished by mounting the stylograph paper on a pendulum (not shown in Fig. 7) which moves the paper horizontally in front of the wire. Thus the spots of successive periods are displaced horizontally and hence are readily distinguishable.

[3] The author is indebted to Prof. B. E. Warren for this suggestion.

FIG. 7. Simple harmonic motion apparatus.

Detailed checking of several important principles is possible. Since the timer allows anaccurate determination of the speed to be made at various parts of the cycle, it is possible to compute the kinetic energy at these points; if the force constant is known, it is also possible to calculate the potential energy. It is then found that the total energy is essentially constant. Similarly the acceleration may be computed for various points of the record and the value of ma computed. If the latter is plotted as a function of the displacement from equilibrium it is found that the points fall quite close to the line given by the force constant, thus checking Newton's second law.

If a plot of displacement *versus* time is made, and a sine curve is fitted at two zeros and a maximum, the difference is almost undiscernible on 8.5×11-in. graph paper. Fig. 8 is a tracing of one of the plots handed in by a student. Fig. 9 shows the corresponding plot of *ma versus* displacement. The points indicated by crosses were obtained in the process of finding the force constant by using 500-g weights. The value of mg is also shown and a subsidiary scale gives the values corresponding to $\overline{cd}-\overline{bc}$. (See Sec. 4.) The following are the values of the kinetic, potential, and total energy, in units of 10^6 ergs, at the points marked A, B and C on Fig. 8:

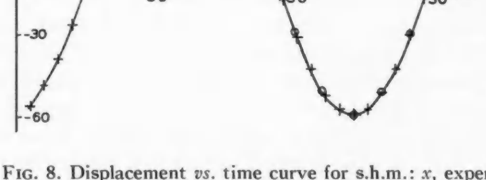

FIG. 8. Displacement *vs.* time curve for s.h.m.: *x*, experimental points; *o*, points for the fitted sine curve.

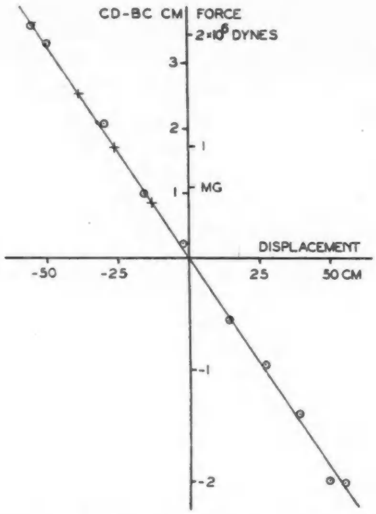

FIG. 9. Plot of *ma vs.* displacement for s.h.m.

	A	B	C
K. E.	0.4	10.4	55.4
P. E.	61.6	51.3	8.4
Total E.	62.0	61.7	63.8

This is representative of the quality of results obtained by the best 20 percent of the class.

The following considerations determined the characteristics of the simple harmonic motion apparatus. The theoretical errors in computing speed and acceleration by the methods of Sec. **4** are about 1 percent for a record of 20 spots/cycle. Twenty-five spots per cycle was considered satisfactory. It is not feasible to operate with a rim-to-wire distance of less than 1–2 mm. Hence the acceleration should be sufficiently large so that a 4 mm error in $\overline{cd}-\overline{bc}$ would not be too much. It was found that with 25 spots/cycle an amplitude of 65 cm gave a maximum value of 4 cm for $\overline{cd}-\overline{bc}$, quite large compared to 4 mm. The overall height of the apparatus was limited to 3.2 m. If the equilibrium position was to be at the middle height, then it is seen that the weight moves from 225 to 95 cm from the end. Since the upper spring must be under greater tension than the lower, it is therefore necessary to obtain springs of sufficient strength, capable of a stretch of roughly 5 times their length. To procure such springs was the most difficult problem met with in building this apparatus. The springs,

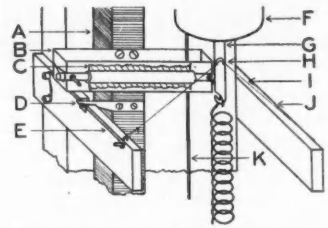

FIG. 10. Releasing mechanism for s.h.m. apparatus.

made of 0.042-in. piano wire, were wound to form 1/2-in. coils with an initial tension between 800 and 1400 g. When these springs were deformed by stretching until the initial tension dropped to zero, they were capable of a stretch of 6 to 7 times their length and had a force constant of about 800 g for unit deformation.

To avoid difficulties of warping, the apparatus was built on a 3.2-m length of 4-in. channel iron. The pendulum which supported the paper was made of a 2.5-m section of 1/2-in. square brass tube pivoted near the top of the channel iron, while the bottom end dipped into a dash pot of heavy oil. It was caused to swing across by rubber bands. Fig. 10 shows the releasing mechanism. The bob F is held down at the desired amplitude by the thread I which is slipped into the notch H in the shaft G on which the bob is mounted. The pendulum A is pulled over to the left and held, against the restoring force furnished by rubber bands, by the hook D. The stylograph paper C is mounted on the bracket B and held by the type of clamp described in Sec. **2**. A similar clamp higher up on the pendulum holds the upper end of the paper. The grounded wire K is just behind the paper. On the back side of the fiber board brace J is mounted a piece of resistance wire against which the thread presses. Closing a switch simultaneously turns on a heating current which burns the thread and applies the output of the spark coil to the bob. When the tension in thread I ceases, the piano wire hook E springs down, thus releasing the pendulum which swings across in roughly the time required for two cycles of the bob. This method of releasing the bob is very satisfactory. It is important to have the plane of the thread parallel to the front face of the channel iron. If this is done and the apparatus is vertical, the bob will oscillate almost indefinitely while main-

taining a rim to wire distance of 1–5 mm. For the first two cycles it can be adjusted to a narrower tolerance.

It is necessary to make an allowance for the mass of the springs, and the effective mass is marked upon the apparatus. The construction of the bob is similar to that of a weight hanger, capable of holding three 500-g weights. By use of these the student can determine the force constant. Thus the only three quantities used in the experiment that are not determined by the student are the mass of the bob, the interval of the timer, and the value of g.

In conclusion, I should like to express my appreciation to Professor F. W. Sears and Mr. H. E. Anderson for their interest and assistance in developing these experiments and preparing this article, and to Mr. Kallenbach of the physics machine shop for the effort and skill he employed in making suitable springs.

Some Uses for the Cathode Ray Oscillograph in an Undergraduate Laboratory Program

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UNDERGRADUATE laboratory courses should offer opportunities for learning beyond those obtained by performing a certain group of experiments. In our laboratories we have found that the interest and knowledge of the *average* student may be increased if the usual experiments are supplemented by short demonstration experiments manipulated by the student under the direction of the instructor. The initiative and manipulative skill of the *more able* student may be encouraged to develop by offering opportunities, beyond the required work, for experimental work in which a particular interest is shown.

In such a program modern equipment should be employed. Particularly useful are small portable cathode ray oscillographs which may be made to serve as central pieces of apparatus for numerous demonstrations and experiments. This type of oscillograph, used with auxiliary equipment in relatively simple and easily connected circuits, will show clearly many physical phenomena previously difficult to demonstrate. The instrument may be used to present integrated pictures and to do quantitative work.

This paper describes and suggests certain basic demonstrations and experiments in which the cathode ray oscillograph is useful. Two types of experiments are described in sound and wave motion, and in alternating current, transient, and thermionic tube circuits. Experiments of type 1 have been found to increase the interest and comprehension of the average student and are, for the most part, qualitative demonstrations. Experiments of type 2 interest the student of more than average ability, are more quantitative and require a better theoretical background.

THE OSCILLOGRAPH

The cathode ray oscillograph is the small portable type now available.[1] All circuits and apparatus are housed in a metal container and one end of the container is a panel on which appear the 3-in. fluorescent screen, input binding posts, and dial controls for the various circuits. The primary power for the whole instrument is furnished by a single connection to the 60-cycle mains.

The cathode ray tube in the instrument has vertical and horizontal deflection plates. There is a suitable amplification circuit for each system with gain control. Focusing and intensity controls provide a sharp, intense spot. A horizontal sweep circuit, continuously variable between 10 and 18,000 cycles/sec., is an integral part of the instrument and synchronization controls make it possible to lock the image. Direct potentials for the various circuits are furnished by suitable rectifier-filter circuits.

[1] RCA, Type TMV-122-B.

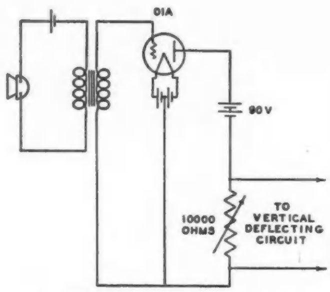

FIG. 1. Circuit for sound and wave motion experiments.

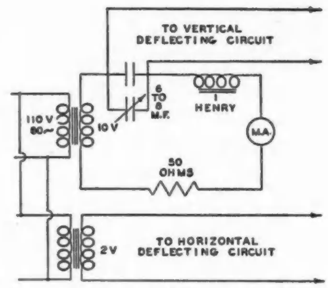

FIG. 2. Phase relations in simple a.c. circuits.

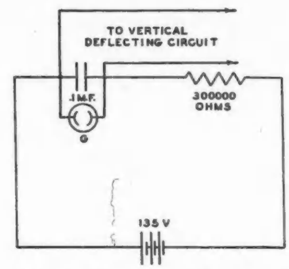

FIG. 3. Circuit to show rise of potential on a condenser.

THE DEMONSTRATIONS AND EXPERIMENTS

I. SOUND AND WAVE MOTION

Type 1 Experiments:

As shown[2] in Fig. 1, a simple telephone transmitter is connected to one stage of amplification. The vertical deflecting system of the oscillograph is connected across the output resistance in the plate circuit. For adjustment of amplitude, this resistance is variable from 0 to 10,000 ohms. Further gain control may be obtained on the panel of the instrument. The spot is sharply focused, and the horizontal sweep circuit is set at a suitable value. With tuning forks of frequencies 256, 512 and 1024, several musical instruments and the voice, the following phenomena in sound are then easily shown:

Pitch. The tuning forks, vibrating, are held in succession before the microphone and the relative number of waves in each pattern noted.

Loudness. One fork is mounted at a fixed distance from the microphone. When the fork is first struck the amplitude of the pattern is noted. As the sound diminishes in intensity, the pattern decreases in amplitude.

Quality. Two forks are sounded simultaneously before the microphone. The complex pattern is compared with the previous simple patterns for single forks. Two different muscial instruments successively sounding the same note produce strikingly different patterns thus showing why each has a distinctive sound. Vowels, consonants and simple words spoken into the microphone produce complex patterns. If references like *Speech and Hearing*[3] are available, these will suggest many other experiments.

Type 2 Experiments:

Lissajous figures. Lissajous figures, difficult to demonstrate with sand pendulums or tuning forks, are easily shown by using both the vertical and horizontal deflecting systems of the cathode ray tube. The student interested in these important phenomena may compute by graphical methods the resultants of two simple harmonic motions at right angles with specified frequencies, amplitudes and phase relationships. To demonstrate the computed figures with the oscillograph, two alternating current circuits are used. One is connected to the horizontal deflecting circuit and, by means of the gain control, the horizontal amplitude is adjusted to the desired value. The other circuit, a phase shifting network, is connected to the vertical deflecting circuit. With the horizontal circuit disconnected, the vertical amplitude is next adjusted. Simultaneous applications of potentials from both circuits will demonstrate the calculated Lissajous figure if the frequency and phase relationships of the two circuits are correct. Fig. 7A shows the Lissajous figure for a 1 : 1 frequency ratio and phase difference of 90°. This experiment stimulates interest in the application of Lissajous figures to the study of alternating current circuit-phase relationships and frequency measurement.

II. SIMPLE ALTERNATING CURRENT AND TRANSIENT CIRCUITS

Type 1 Experiments:

In these experiments, the voltage to be tested is connected directly to the vertical deflecting system, and the horizontal sweep circuit is set at some sub-multiple of the input frequency. For study of any particular wave form, the pattern may be locked by means of the synchronization control.

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[2] For simplicity, auxiliary circuits only will be shown with leads to the oscillograph labeled.

[3] Fletcher, *Speech and Hearing* (Van Nostrand, 1929).

Frequency and wave form. Alternating current generators of various frequencies are connected successively to the vertical deflecting circuit of the oscillograph. Suggested frequencies are 60, 240 and 600 cycles. With the sweep circuit kept at the same frequency (slight adjustments may be necessary to make the image stand clear) the relative number of waves in each pattern is determined and the fact that the patterns are sinusoidal is noted. A machine that shows a pronounced harmonic distortion may then be connected. The sweep frequency is increased to spread the wave, and the image is locked to facilitate the examination of the harmonics.

Type 2 Experiments:

Phase relations in the simple a.c. circuit. The student who has previously shown an interest in Lissajous figures may be given an opportunity to apply them to alternating current circuit problems. For a first experiment, the circuits shown in Fig. 2 may be used. Voltages for both circuits are funished from a common 60-cycle, 110-volt source through small step-down transformers. One circuit sweeps the spot horizontally. The other is the circuit to be tested. Leads from the inductance, capacitance or resistance of this circuit are connected to the vertical deflecting system. The resulting Lissajous figures give the phase relationships between the line voltage and the test voltage.

An interesting demonstration of phase relationships in series resonance can be shown with the same circuit. The vertical deflecting plates are connected across the resistance in the circuit and, with the circuit not in resonance, a typical inclined ellipse appears. When the circuit is adjusted to resonance by adjusting the capacitance, this ellipse becomes a straight line thus showing that the line voltage and the voltage across the resistance are in phase. Connection to the capacitance or inductance results in an oscillogram like Fig. 7A, which shows the 90-degree phase difference between the line voltage and the voltage on the inductance or capacitance at resonance.

Transient circuits. Transient phenomena can be shown if the correct circuit constants are selected, and the phenomena are made to repeat periodically. Fig. 7B shows the rise of potential

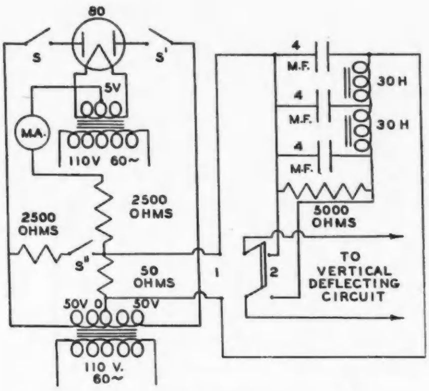


FIG. 4. Diode rectifier circuit with filter unit.

on a condenser in a circuit containing resistance and capacitance in series. The circuit is shown in Fig. 3. A small neon glow lamp G is connected across the condenser. This lamp will conduct, and immediately discharge the condenser, when the voltage across the latter reaches a definite value. The process will thus repeat itself at regular intervals and if the sweep frequency of the oscillograph is set at the proper value, the image may be locked and the curve examined at leisure or photographed.

III. Thermionic Vacuum Tube Phenomena

Type 1 Experiments:

The two-electrode tube as a rectifier. Fig. 4 is the circuit used to show half-wave and full-wave rectification by means of a two-electrode vacuum tube. To avoid danger due to high voltage in a circuit with open wiring which is handled by large groups, the plate voltage transformer has a 50–0–50 volt secondary. The plate circuit load is a 2500-ohm resistor, and the potential for the oscillograph is taken across a 50-ohm series resistor. The sweep circuit is set at a value suitable to give a locked image of several waves. With the DPDT switch set at position 1 and switches S' and S'' open, close switch S and the half-wave pattern appears. For the full-wave pattern, close S' also. To compare with the a.c. pattern, open S and S', and close S''.

Filter circuits. The smoothing action of a two-section filter may be shown by putting the DPDT switch in position 2.

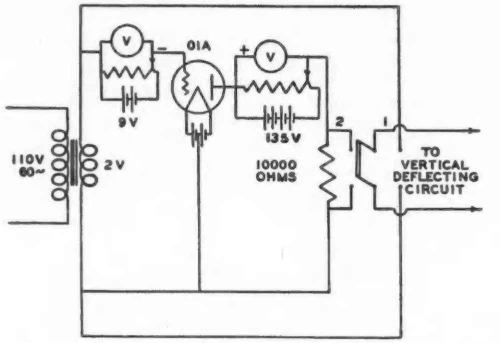


FIG. 5. Triode circuit to demonstrate "detector action" and amplification.

The three-electrode tube as a "detector" and amplifier. Fig. 5 is a circuit that can be used to show "detector action" and amplification by means of a three-electrode vacuum tube.

To show detector action, the grid potential is set at −6 volts, and the plate potential at 20 volts. With the DPDT switch in position 1, the pattern of the input alternating potential on the grid appears. With the switch in position 2, Fig. 7C appears. This oscillogram shows that when the grid is highly negative, only the positive half of the alternating current cycle is effective in changing the plate current and that under these conditions the tube is functioning essentially as a rectifier.

To show amplification, the grid potential is set at 0, the plate potential at 90 volts. With the switch in position 1, the pattern of the input alternating potential appears. When it is in position 2, the amplified pattern due to the action of the vacuum tube appears. Fig. 7D, a double exposure, shows the results of an experiment of this type.

The three-electrode tube as an oscillator. Fig. 6 shows a simple Hartley oscillator circuit which generates an audiofrequency. By listening in on the telephone *T*, the note can be heard at the same time that the wave form can be seen on the oscillograph screen. For a large group, an amplifier and loudspeaker may be used instead of the telephone receiver. Experiments on the relation of frequency, inductance and capacitance may be performed. For example, by connecting the proper capacitance in parallel with the 1-μf condenser, the frequency may be halved.

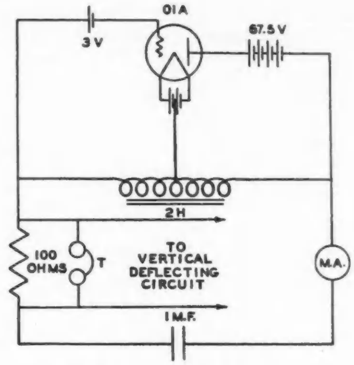


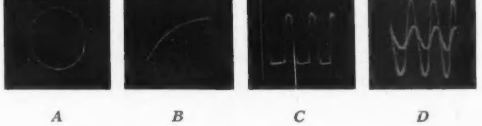
FIG. 6. Simple Hartley oscillator circuit.

Type 2 Experiments:

The circuits used in connection with the foregoing Type 1 experiments may be used for a number of quantitative experiments. Students interested in radio and vacuum tubes always have in mind a number of circuits which they are eager to set up and test. The literature[4] will suggest other experiments. The following are possible projects.

Filter circuit design. A filter circuit for a particular rectifier may be designed and its efficiency tested with the oscillograph. Various types of filter circuits may be set up and their relative effectiveness determined.

Amplification measurements; amplifier design and testing. With a table of tube constants, the theoretical voltage amplification of one-stage amplifier circuits built around several types of three- and multi-electrode vacuum tubes may be computed. The proper circuits may then be connected and tested with the oscillograph. To measure the voltage amplification for the case discussed in connection with Fig. 5, for example,



A *B* *C* *D*

FIG. 7. Photographs of locked images on the oscillograph screen.

[4] J. H. Morecroft, *Principles of Radio Communication*, ed. 3 (Wiley, 1933); F. E. Terman, *Radio Engineering* (McGraw-Hill, 1932); K. Henney, *Electron Tubes in Industry* (McGraw-Hill, 1934).

disconnect the horizontal sweep circuit and let the applied voltage sweep a vertical line on the oscillograph. The length of this line is proportional to the input voltage. The ratio of the lengths of this line for the DPDT switch in position 2, then position 1, is the voltage amplification.

As a more elaborate project, a multi-stage audiofrequency amplifier may be designed to meet definite specifications, then constructed. The completed circuit may be tested for audio distortion with the oscillograph and a calibrated variable audiofrequency oscillator.

Frequency measurements and oscillator circuits. By means of Lissajous figures, accurate frequency measurements may be made through a wide range of frequencies. Up to 10^5 cycles, frequency may be measured by using the horizontal sweep circuit synchronized by an external standard frequency voltage. To make frequency measurements, several types of audio and radio frequency oscillators are set up. As a project, a variable frequency oscillator may be designed to work in a definite frequency range. When constructed, it may be calibrated with the oscillograph.

In conclusion, the experiments and demonstrations described and suggested here are just a few of many which are possible, and not all are intended for the beginning course. Many of the more difficult experiments are suitable for intermediate courses in electrical measurements, and vacuum tube and high frequency circuits. One project, such as the design, construction and testing of an amplifier circuit, rightly undertaken, might well occupy the attention of a student for a whole laboratory course along with the required work of the course. The more difficult projects should be assigned only to students of ability who are willing to do the necessary reading and are eager to attempt an experimental problem with a minimum of direction. Such students should be encouraged to cultivate initiative, interest and enthusiasm through creative effort.

Teaching the Concept of Optical Imagery

Paul K. Taylor, *State Teachers College, Minot, North Dakota*

A GOOD deal of care and simplicity must be used in the presentation of the subject of optical imagery if beginners are to obtain a clear and workable knowledge of image formation and location. I have obtained excellent response from students by the method of presentation I have gradually developed. Since it is not given explicitly or completely in any of at least twelve commonly used college textbooks I have recently examined, it is presented here in abbreviated form for the consideration of other teachers of beginning physics.

When light falls upon a visible object, some of it is absorbed and the remainder is diffusely reflected. If we imagine the surface of the object to be divided into millions of tiny surfaces, light from each of these will still be scattered in all directions, but the amounts of light reflected from the various elemental surfaces will differ in accordance with their relative reflecting and absorbing abilities. Thus are produced the varying lights and shades as well as the different colors by which we distinguish one portion of a body from other portions or one object from another. This reasoning holds equally well for a self-luminous object except, of course, that the light emitted from each of the tiny areas originates in the body itself rather than being reflected by it.

When we speak of an *image* of an object, we mean, of course, a real or apparent visual reproduction of the object. It will simplify our concept of how the *whole* image is formed if we consider it to be composed of all the images, both as to intensity, color, and shape, of the individual tiny reflecting or emitting surfaces into which we have already imagined the body to be divided. Let it be assumed that each of these elemental surfaces has been chosen small enough so that, for the practical purpose of vision, it will be seen as a point. We shall now consider the formation of the image of one of these "points" and our reasoning will apply equally well to the formation of the images of all the other "points," the sum

total of which, arranged in corresponding order, forms the complete image of the object.

Since light is scattered in every external direction from each of the points of an object, that which enters a refracting or reflecting instrument, in each case through a circular opening or aperture, will be seen to be contained in a cone, the base of which is the aperture of the instrument and whose vertex is the point of the object from which proceeds the light. Light from each object-point is thus diverging as it proceeds to the optical instrument.

If the instrument can so act upon this divergent light as to cause it, either actually or apparently, to be spreading to the eye from some *different* point than the original one, then, perforce, we will see an image of the object-point at this position. If the light *actually* diverges to the eye from the new position, we say a *real* image is formed there. If it only *apparently* spreads to the eye from the new position, we say, appropriately, the image is *virtual*. The processes of reflection or refraction (or, less commonly, diffraction and interference) are those used in optical instruments to effect such a change in the light falling upon them. For example, a lens, thinnest at its center, each of whose faces is a portion of a sphere, will, by the process of refraction, cause diverging light after passing through it to spread at a greater angle than it was before incidence so that the emergent rays *appear* to come from a point closer to the lens than the object: hence we say a *virtual* image exists at this new position. If, instead, the lens is convex, it will tend to overcome the spreading of the light incident upon it and even to make it *converge* to a point on the opposite side of the lens from the object. On the *far* side of this point the light will again be *actually* spreading out to the eye as it was from the original object-point. Hence we say a *real* image is formed at this new position.

Most authors content themselves, in this case, with drawing rays from the lens merely *to* the point of convergence rather than *extending them through it* with arrows on the far ends. This practice is apt to confuse students for they do not understand why a reproduction of an object-point should be formed where light rays *come together* when we have already taught them that one sees an object-point because light rays *diverge* from it to the eye. Many authors also define two or three rays which, by the laws of reflection or refraction, *can* be drawn from an object-point, yet do not bother to state why it is *necessary*, as I have set forth herein, to draw divergent rays from an object-point and trace them through the optical system in order to locate the image-point. Moreover, they fail completely to mention that, once the junction of these two or three rays has been established, any of the infinite number of rays spreading from the object-point in such a direction as to strike the lens or mirror will, after being acted upon by it, pass through the *same* meeting point. This is an essential concept in the case of multiple-image formation as in a telescope or microscope in which some of the "construction" rays used to locate the second image usually have to be drawn in such a direction that they could not possibly have been contained in the original beam of light incident upon the instrument. Yet, once the second image-point is located, those same rays which were used to locate the first image may be at once extended to pass through (or appear to come from) the second image position.

There is another case of real-image formation which should be explained here—that of images formed on a screen, as with a projection lantern. Here an image-point is formed at the same position from which, in absence of the screen, rays would again be diverging to an eye still more distant from the lens. Since, with the screen in position, however, no further divergence beyond it is possible, the method we have already discussed seems not to apply. In this case, we must remember, as stated at the outset, that the quantity and character of the light diverging in a cone from each of the tiny surfaces or "points" of the object depend upon the relative brightness and color of these surfaces. Hence, each corresponding point of convergence of the light upon the screen will have a proportional quantity of light of the same color striking upon it. The whole image, which is the composite of the millions of images of individual object-points, each arranged to be adjacent to the same points as in the object, will therefore present to the eye the same surface appearance as did the whole of the original object and is therefore its visual reproduction or image.

In this presentation it will be noticed that detailed explanation, even verbosity, rather than conciseness of statement is encouraged. In so doing I align myself with those who believe that many of our students would gain clearer concepts and thus be able to develop more interest in physics in general if we, as teachers, should not hesitate to go to the very foundations in explaining each phenomenon.

APPARATUS, DEMONSTRATIONS AND LABORATORY METHODS

Special Exploring Coil Method of Measuring Magnetic Fields

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THE paper outlines a modification of the ordinary exploring-coil method of measuring field strength, in which the coil is employed first with the field to be measured and then with a standard solenoid. The use of the same coil for each case obviates the necessity of knowing the number of turns in the coil and the mean area. This makes the method particularly useful for elementary laboratory work.

Description of apparatus. The details of the apparatus are illustrated in Fig. 1. A vertical brass rod R supports a standard Q. The latter carries an arm A which is pivoted at B. A small coil spring S connects the vertical rod and the arm, and a small pin P is provided so that the arm may be held in a horizontal position against the tension of the spring. Pulling the pin P allows the arm to rotate up into a vertical position. The electrical connections leading from the coil terminals to the binding posts of the holder A consist of two silk covered wires twisted tightly together.

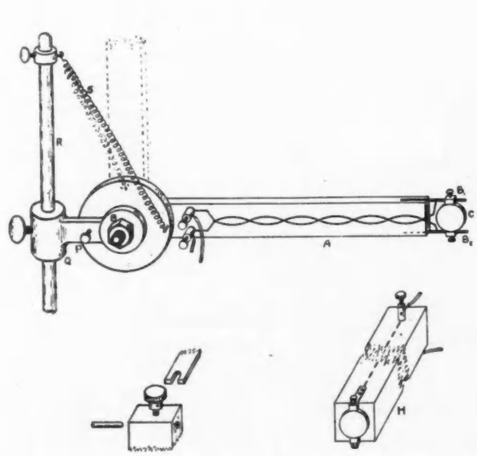

FIG. 1. Apparatus, with details of coil connections.

The exploring coil C consists of 350 turns of No. 40 silk-covered copper wire wound on a fiber bobbin. The average diameter of the winding is 1.18 cm. The terminals of the winding are soldered to two brass blocks B_1 and B_2 which also act as supports for the coil. These blocks are designed so that the exploring coil may be supported either on the rotating arm A or at the end of a wooden rod H which is provided with suitable clips and binding posts. This rod, which is 35 cm long, is employed to support the coil in the center of a standard solenoid when measurements are made with reference to the solenoid.

Experimental method. For one series of measurements the coil was supported in the central portion of a standard solenoid coil and connected in series with a sensitive ballistic galvanometer. The galvanometer deflection produced when the current in the solenoid was broken, was measured for various values of the current and an average value d of the galvanometer deflection per unit current in the solenoid was determined. In order to prevent excessive damping a special combination, double-pole switch and galvanometer cut-out key was employed to open-circuit the galvanometer just after the current in the solenoid was broken. Let r represent the resistance of the galvanometer circuit, and h, the field strength per unit current.

Another series of measurements was made in which the coil was flipped out of the field between the poles of a large electromagnet by means of the apparatus of Fig. 1. For this part of the work a fairly large resistance was connected in series with the coil and galvanometer, so the cut-out key was not required. Let D represent the galvanometer deflection for the field H of the electromagnet, and R, the resistance in the galvanometer circuit.

TABLE I. *Comparison of three methods of measuring magnetic field strength.*

Electromagnet current (Amp.)	Field of electromagnet gap ($\times 10^3$ gauss) Exploring coil	Fluxmeter	E.m. balance
0.10	0.831		
0.15	1.12	1.14	
0.25	1.78	1.76	
0.40	2.51	2.52	
0.50	3.03	3.04	
0.70	4.14	4.17	4.10
1.00	5.42	5.60	5.47
1.50	6.47	6.50	6.40
2.00	7.16	7.40	7.04
2.50	7.58	7.90	7.43

The deflections produced vary directly as the field strength and inversely as the resistance, since the same coil and galvanometer are employed in each case. Hence

$$D/d = Hr/hR. \tag{1}$$

The foregoing method was employed for a series of measurements of the field of an electromagnet gap. The standard solenoid employed had a winding 57.7 cm long with 3650 turns. The corresponding values for h, r and d of Eq. (1) were 79.5 gauss, 878 ohms and 8.58 cm respectively. The value of R was 15,000 ohms for current values in the electromagnet of 0.5 amp. or less, and 20,000 ohms for higher current values. The determinations for H appear in the second column of Table I. For purposes of comparison values are given for H as determined by a fluxmeter and also by means of an electromagnetic balance.[1] Neither method proved suitable for checking the smaller values of H. The values secured indicate that the method is well suited for measurement of magnetic field strength except for the higher values.

[1] D. S. Ainslie, R. S. I. **4**, 546–548 (1933).

An Inexpensive Millikan Oil-Drop Apparatus

C. C. KIPLINGER, *West Liberty State Teachers College, West Liberty, West Virginia*

THE great value of bringing undergraduates into early contact with the methods, atmosphere and philosophy of modern research in physics seems beyond question. Owing to the relatively high cost of reproducing the expensive apparatus used in many experiments of historical importance, the average laboratory is markedly circumscribed in this field. However, it is not necessary entirely to relinquish such an excellent objective, as I shall try to point out in the case of the famous Millikan oil-drop experiment. Herewith described is an oil-drop apparatus (Fig. 1) which we built at negligible cost. It has been given a permanent location in the photometer room and is always ready for demonstration. Having been in use for several years, its worth has been fully demonstrated.

The source of illumination is a 400-watt projection lamp. Its housing is made from a square tin cracker can. We also have used a 200-watt clear-bulb lamp of the ordinary type with excellent results. An aquarium filled with distilled water absorbs the heat from the 400-watt lamp. This is not needed for the 200-watt lamp, as the condensing lens, a 500-ml florence flask filled with distilled water, usually absorbs enough heat to prevent convection currents within the cell.

Details of the oil-drop chamber and cell are shown in Figs. 2 and 3. The cell consists of two plates of 18-gage brass 5 cm square. To the upper side of the upper plate is soldered a short length of 2-cm brass tubing. At the bottom of the tube

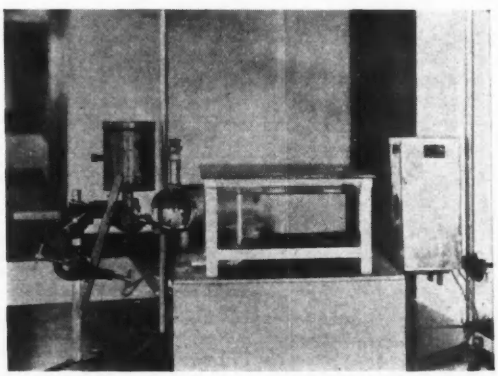

FIG. 1. Photograph of assembled apparatus.

three or four small holes are drilled in the plate. A 1-lb coffee tin is fitted with a tubular outlet on the bottom which fits the brass tube. The tin is also provided with a side orifice into which the oil is sprayed with an oil atomizer. For some of our experiments we have used kerosene in an ordinary perfume atomizer with fair results, despite the volatility of the oil. An electrical connector is soldered on the tube side of the upper plate.

A connector is likewise soldered to the underside of the lower plate. On the upper side of this plate is cemented a plate of Bakelite 4 mm thick and of like dimensions, the center of which has been cut out to form a cylindrical chamber 2 cm in diameter. Channels 4 mm wide are cut 90 degrees apart in the walls of the chamber so as to furnish windows for the telemicroscope and the light beam. These windows are covered with bits of plate glass cemented on, but cellophane would serve as well.

A rubber gasket cut from a bit of inner tube is used under the upper plate to render the cell airtight and a clamp constructed of two oak strips held together by a bolt and thumb-screw holds the two plates in proper alignment and also furnishes the supporting arm.

Three or four 45-volt "B" batteries serve nicely for the source of potential. We use a "B" eliminator costing about $4 and furnishing 300 volts. The telemicroscope, the most costly part of the equipment if of standard type, may consist of the eyepiece section of a spyglass with a narrow strip of cellophane cemented across the field at the focus of the lens nearest the eye. This will give two fiducial lines between which the speeds of the drops may be measured. A low power standard microscope objective and a high power eyepiece, the latter fitted with the cellophane as indicated, mounted in a 10-in. brass tube, will prove the best and cheapest telemicroscope available. It may be that the optical equipment of certain cheap microscopes handled by mail order houses will be found to be satisfactory for this purpose. We have used a magnification of 60 diameters for almost all of our work.

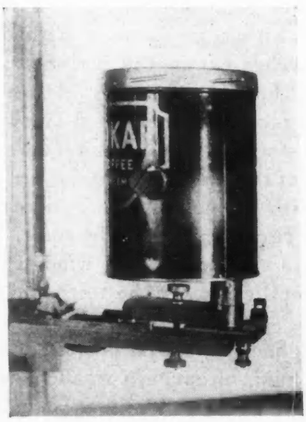

FIG. 2. The oil-drop chamber.

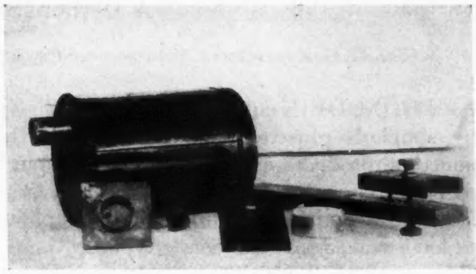

FIG. 3. Details of the oil-drop chamber and cell.

Timing has been done with various devices. The Harrington timer[1] is preferred, but expensive. The stop-watch is standard. On one occasion, with all of the watches out of commission, a metronome adjusted to beat 180 per min. was used together with a counter. The results were quite satisfactory.

A β-ray capsule may be placed in the large chamber to furnish an additional source of electrons.

The reactions of the many students who have performed this experiment with the equipment described lead us to believe that it is one of the most valuable in our collection. The electron as a physical concept acquires a new meaning and the underlying philosophy challenges the imagination of the youthful physicist-in-the-making.

[1] E. L. Harrington, Am. Phys. Teacher 2, 170 (1934).

A Demonstration Phonodeik

G. G. Kretschmar, *Department of Physics, Walla Walla College, College Place, Washington*

A PHONODEIK equipment that is relatively simple to construct and set up, and at the same time produces a wave form large enough and bright enough to be seen clearly by a large class, can be built up around an audio amplifier and loudspeaker of the dynamic type.

The phonodeik element is constructed essentially as suggested by Miller[1] except that the cone of the loudspeaker replaces the thin diaphragm of his original instrument. The power available with the electrical reproduction makes it possible to have the spindle and mirror larger and stronger, than in Miller's instrument, which greatly simplifies the construction and adjustment.

In our instrument the mirror is 3×5 mm and is waxed to a small spindle 1 mm in diameter and 13 mm long. The spindle is of steel which has been hardened. A small pulley about 5 mm in diameter and 1 mm wide is made on the spindle. A silk thread is attached to the cone; it makes a single loop over the pulley and is held taut by a fine spring. The spindle pivots are supported in plain brass bearings made by drilling No. 72 holes in the side pieces of the supporting stirrup.

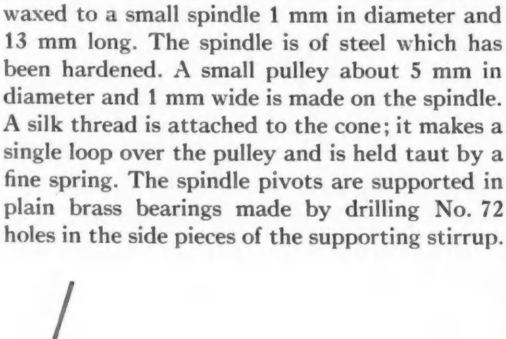

Fig. 1. Diagram showing arrangement of phonodeik.

The mounting is a ½-in. square brass bar which is attached on the two opposite sides of the speaker cone support.

An arc light makes a satisfactory light source. It is enclosed so that the light is emitted only from a hole about 8 mm in diameter. Fig. 1 shows an arrangement of the equipment that has been found to produce good waves of about 1 m

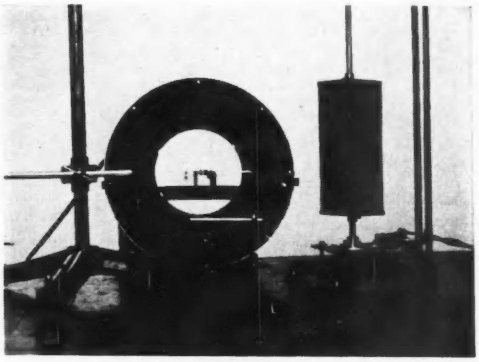

Fig. 2. Photograph showing details of phonodeik.

amplitude. Fig. 2, which was taken from the position of the arc light, shows the general positions of the lens and rotating mirror.

The rotating mirror should be rather long and narrow, and may have four, or better, six sides, each, say, 5×30 cm. It should be motor driven. A speed of 2 rev./sec. is satisfactory. It is convenient to use a small direct-connected synchronous motor of the "electric-clock" type, similar to the one seen attached to the base of the mirror in Fig. 2.

Some details of the driving motor may be of interest. The rotor is a disk of soft steel 3 mm thick and 7.6 cm in diameter with 60 equally spaced notches cut in the periphery. The coil is designed for 110 volts, 60 cycle, and consists of 2000 turns of No. 30 enameled wire wound on a bar of transformer sheets 15 mm square. The pole pieces are of the same material as the rotor, are notched with the same spacing, and each covers 90° of the circumference of the rotor. The rotor itself has a "squirrel-cage" winding made of babbitt metal cast over the teeth and turned to form.

The amplifier should be of good quality and free from hum, although a small hum will not seriously interfere with its use for demonstration purposes. Any type of audio input may be used; a phonograph pick-up or the input from a microphone source is convenient.

[1] *The Science of Musical Sounds* (Macmillan, 1922), p. 79.

High Acoustic Output from Tube-Driven Tuning Forks

CHAS. WILLIAMSON AND W. J. EISENBEIS, *Carnegie Institute of Technology, Pittsburgh, Pennsylvania*

LECTURERS in physics often use large tuning forks mounted on resonators when demonstrating beats, sympathetic vibrations, consonance and dissonance, justly intoned and equally tempered intervals, and so forth. Such demonstrations are facilitated if means are at hand for maintaining steady oscillations of large amplitude. The vibrator-type electromagnetic drive[1] will do this when in proper adjustment, but it is somewhat unreliable and noisy in operation, and the contactor loads and mistunes the fork appreciably. Recent workers[2] have directed their efforts chiefly toward the attainment of good frequency stability, and have usually been limited to whatever amplitude was consistent with this end.

The two circuits here described are self-starting, and will maintain either large or moderate amplitudes for long periods of time without appreciable change. No tuning is needed, nor is the fork mechanically loaded. Each circuit uses an acoustic link. In the first arrangement, the pick-up is by microphone (the conventional telephone transmitter), and the drive is electromagnetic. This circuit will drive forks of frequencies between 128 and 1024 d.v./sec. without any change in apparatus, and will maintain amplitudes which may be so large that the sound output cannot be tolerated for long. In the second arrangement, the pick-up is electromagnetic, the drive by loudspeaker. This circuit is desirable for use in the presence of a large audience. Some distortion is introduced by the loudspeaker, but in demonstrations involving consonant and dissonant intervals this is an advantage.[3]

Fig. 1 shows the circuit diagram of the first arrangement. Power is supplied from the 110-volt d.c. line. This accounts for the use of the interesting and highly efficient types of tubes specified. The circuit may of course be redesigned for 110 volts a.c., but very good filtering will be needed to prevent stray beat effects. The only special piece of apparatus is the electromagnet. Its core, made from stampings taken from an audio-frequency transformer, has a cross section of 2 cm^2 and is wound with 4500 turns of No. 36 enamel-and-cotton-covered copper wire, tapped at 1000 and 2500 turns from the start of winding. Other details are shown in Figs. 2 and 3. The drive, as usual, is applied to the fork at a point that will minimize the generation of the first overtone. If the drive is applied instead at the tips of the fork prongs, it is possible to damp the fork lightly at the nodal point and generate oscillations in which the first overtone predominates.

The design chosen permits plenty of milliampere-turns without appreciable heating or magnetic saturation, allows the use of large air-gaps, and applies the drive equally to both prongs of the fork, thus avoiding unsymmetrical bending-moment at the stem. It can be employed with forks mounted in any position, with or without resonators. Most of the forks that we use (manufactured by Max Kohl, after designs by R. Koenig) have approximately the same prong-separation; they differ mainly in length. Hence a given separation of the adjustable pole-tips will suit them all fairly well. An increase in maximum amplitude is obtained by the proper choice of taps on the electromagnet; but any number of turns chosen at random from those provided will drive most of our forks satisfactorily.

Ordinarily it is best to put the microphone close to the tips of the fork prongs, or near the mouth of the resonator.

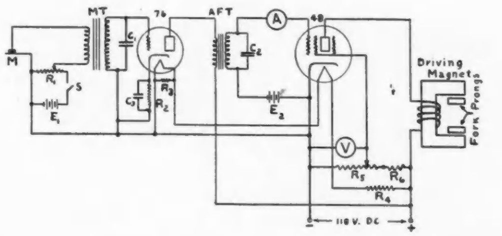

FIG. 1. Circuit diagram. S, S.P.S.T. switch; A, 0–1.5 milliammeter; V, 0–150 voltmeter; M, single button microphone; E_1, 6-volt microphone battery; E_2, 22.5-volt bias battery; MT, microphone input transformer; AFT, 3-to-1 audio transformer; C_1, 0.006μf; C_2, 0.003μf; C_3, 4μf; R_1, 400Ω; R_2, 1000Ω; R_3, 60Ω, 10 watt; R_4, 50-watt tungsten lamp; R_5, 10^4Ω; R_6, 1500Ω. The fixed condensers C_1 and C_2 are used to suppress parasitic oscillations; their rating must be determined by trial, the smallest that will do the work being chosen.

[1] Helmholtz, *Sensations of Tone*, tr. by Ellis (Longmans, Green, 1912), p. 121.
[2] Klein and Rouse, J.O.S.A. and R.S.I. **14**, 263 (1927).
[3] Helmholtz, reference 1, p. 180.

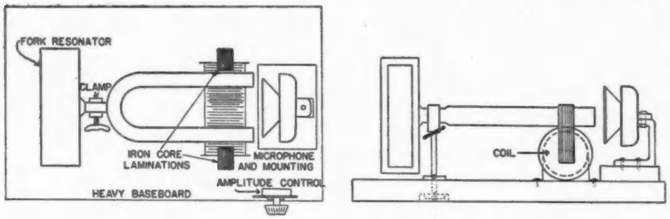

FIG. 2. Plan and elevation of electromagnetic tuning fork.

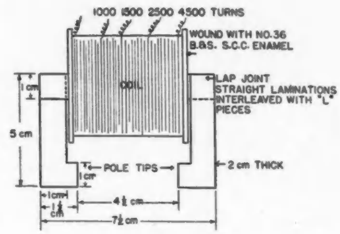

FIG. 3. Coil assembly.

Regions will be found, especially when high-frequency forks are being used, within which the impulses picked up by the microphone are anti-resonant in phase, and oscillations will not build up at all. It is instructive and interesting to allow the fork to build up to a large amplitude when the microphone is favorably located, and then suddenly to damp out the oscillations by moving the microphone to an anti-resonant position. This is especially effective if the second position is nearer the fork than is the first.

Owing to the regenerative effect of the circuit, a conventional gain-control will not operate properly. For example, if a control-grid potentiometer is employed with either tube, as soon as it is set high enough to permit any appreciable building-up of oscillations, the circuit "runs away" and loads the output tube to capacity. This has been noted[2] as a disadvantage inherent in the operation of tube-driven forks. However, it can be overcome very simply. If we limit the load-handling ability of either tube, we provide a "bottleneck" which holds the output power down to a definite amount, no matter what the input may be. The screen-grid potentiometer R_5 shown in Fig. 1 does this well, permitting the steady maintenance of oscillations of any amplitude down to 0.3 of maximum.

Measurements of power input to the electromagnet were made with a tube milliwattmeter[4] using a 6A6 double triode. The 48 tube delivered a maximum of 0.8 watt when driving our 256-cycle fork. The circuit was then rearranged so as to provide for separate excitation from an a.f. oscillator, and the same maximum of 0.8 watt was observed. This was done in order that readings might be taken either when the fork was vibrating freely or when it was clamped to prevent motion. In the latter case the power input fell to 0.6 watt. Two thousand turns of the coil, having a d.c. resistance of 450 ohms, were then being used. The following constants were measured at 256 cycles with the fork in place but not vibrating, and no d.c. in the coil: impedance, 1670 ohms; reactance, 1070 ohms; a.c. resistance, 1300 ohms; inductance, 0.665 henry; phase angle, 39.5°.

The necessary d.c. excitation of the electromagnet[5, 6] is furnished automatically by the plate current of the output tube. Harmonic distortion would be decreased and efficiency improved if means were provided for augmenting the steady component of magnetic flux. It is well known that the force exerted by a magnet upon an object at a fixed distance is given by

$$F = kB^2, \tag{1}$$

where B is the induction and k is a constant. Now the plate current of the output tube in Fig. 1 is represented by $I_p = I_0 + I_1 \sin \omega t$, for small variations. Hence, provided that the incremental permeability of the iron in the magnetic circuit is sensibly constant, $B = B_0 + B_1 \sin \omega t$. Thus $F = k(B_0^2 + \frac{1}{2}B_1^2) + 2kB_0B_1 \sin \omega t - (kB_1^2 \cos 2\omega t)/2$. This result, familiar to telephone engineers, applies to the tube-driven fork just after oscillations begin, but before they have time to build up to a large amplitude. We have a steady component, a cyclic component of the desired frequency, and one of double frequency which is not wanted. It will be observed that B_0 acts as an "amplifier" of the useful sine component, but leaves the undesired cosine term unchanged. Hence it will pay to use as large a value of B_0 as convenient, provided that B_1 remains practically unaltered. In seeking to do this we are experimenting with a modification of Dye's magnet[2] in which the steady flux is supplied by an additional winding. With this arrangement, upon which we hope to report later, we find that the low-frequency forks drive just as well, and the high ones much better.

It should be noted that k in Eq. (1) will not be constant if the amplitude of vibration is large in comparison with the air-gap. Moreover, when maximum power output is desired, hysteresis in the iron and plate-circuit distortion

[4] Turner and McNamara, Proc. I. R. E. **18**, No. 10, 1743 (1930).

[5] Mills, *Radio Communication* (McGraw-Hill, 1917), p. 27.

[6] Kennelly, *Electrical Vibration Instruments* (Macmillan, 1923), Chap. II.

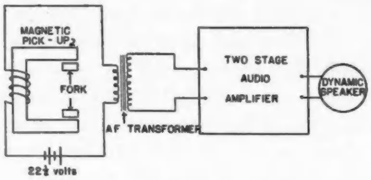

FIG. 4. Loudspeaker drive.

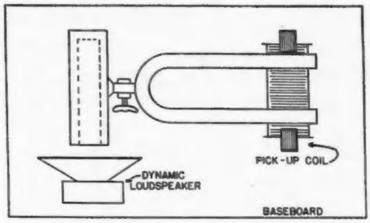

FIG. 5. Plan of loudspeaker drive.

in the tube will make linear operation out of the question. Fortunately the decrement of a good fork is so small that distortion in the periodic impulses of the drive will not cause the motion of the fork itself to depart seriously from the sine form.

Figs. 4 and 5 show the second arrangement, that using the dynamic loudspeaker drive. The electromagnet previously described is now used as pick-up, being coupled to the amplifier with the aid of an ordinary a.f. transformer. There being no special advantage in the use of a single output tube—in contrast to the situation in Fig. 1—it is permissible to employ the usual push-pull output stage. In fact, any two-stage audio amplifier with adequate power output may be used. It is best to provide the amplifier with one of the special gain-controls described above, for the reason already cited. Resonator-mounted forks of frequencies 128 to 1024 have been readily driven by this circuit. As previously noted, antiresonant phase conditions may occur, especially with high-frequency forks; they can be avoided by moving the loudspeaker toward or away from the mouth of the resonance-box (Fig. 5).

Either type of drive will serve equally well for most demonstrations. The forks acquire a definite magnetic polarity, which should be marked for future use. In case a high-frequency fork will not start promptly, the clamp should be loosened a little. The antinodal vibrations of the stem must not be overdamped.

We gratefully acknowledge the assistance of Mr. A. W. Raspet, who did much of the preliminary experimental work.

An Advanced Laboratory Experiment on the Ionization Potential of Mercury

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IN an advanced laboratory course in electronics it is desirable to include an experiment involving critical collisions of electrons with atoms and molecules, the direct result of which is the determination of the ionization potential of a vapor. In general, experiments of the type of Lenard and of Franck and Hertz[1] require the construction of a tube of special design, and are therefore unsatisfactory for routine use in the average teaching laboratory where a vacuum system, liquid air, and the services of a glassblower are not readily available. Furthermore, such special tubes deteriorate rapidly and necessitate repetition of the costly and time-consuming process of reconditioning. These disadvantages would be eliminated if a commercial radio tube could be employed. The author has modified the method of Found[2] so that an RCA type-82 radio tube and quite simple auxiliary apparatus are the only requisites. The resulting experiment has proven very satisfactory, not only because it is inexpensive but because it may make a considerable contribution to the students' knowledge of electronics.

Found's method[2] utilizes the fact that, in a two-element tube, the presence of positive ions in the region of the filament reduces the space charge to such an extent that the space current is considerably greater than the values pre-

[1] Bull. National Research Council **9**, (1924).

[2] Phys. Rev. **16**, 41 (1920).

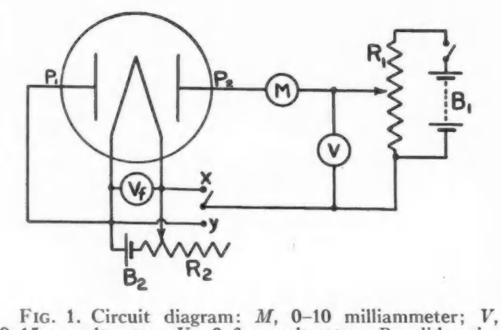

FIG. 1. Circuit diagram: M, 0–10 milliammeter; V, 0–15 v voltmeter; V_f, 0–3 v voltmeter; R_1, slide wire resistance, ca. 2500 ohm; B_1, 22.5-v "B" battery; B_2, storage battery; R_2, resistance for controlling filament current; x, y, poles of a DPST knife switch.

dicted by the Child-Langmuir equation.[3] The minimum ionizing potential is then determined from the point of the graph of I *vs.* $V^{\frac{3}{2}}$ at which the current first deviates from the linear relation.[3] Therefore it is important for the student to demonstrate, with the same apparatus used in determining the ionization potential, that the Child-Langmuir equation would be obeyed if the atomic or molecular vapor were not present. The procedure is as follows.

The RCA 82 is a full-wave mercury vapor rectifier tube; it may be purchased in most radio stores for less than a dollar. External connections are made as shown in Fig. 1. The plate not used, P_1, is connected to any part of the filament circuit. A milliammeter M is chosen whose resistance is so small (a 1-ohm meter is usually employed) that the IR drop over the meter is negligible (say 0.1 percent) in comparison with the voltage V. If a meter of larger resistance is used a correction should be made for each value of V.

The tube is mounted base up in a socket which is supported far enough above the table top so that the glass bulb may be immersed in a suitable bath. During the first part of the experiment the lower half of the bulb is immersed in a refrigerant consisting of liquid air or of solid carbon dioxide in equal weights of chloroform and carbon tetrachloride. Entirely satisfactory data have been obtained with an ice-salt-water bath at $-8°$ to $-10°$C. It is important, however, to use a vessel large enough so that the mixture about the walls of the tube may be stirred constantly. The accelerating potential V is varied from 0 to 15 volts and the space current I is recorded for each value of V. It can be seen from Fig. 1 that the true accelerating potential is not V but is $V-V_0$, where V_0 is a constant due to the IR drop along the filament, contact potential, etc. The value of V_0 can be easily determined graphically if the data are plotted as $I^{\frac{2}{3}}$ *vs.* V, instead of the form I *vs.* $V^{\frac{3}{2}}$ in which the Child-Langmuir equation usually is written. The points should lie on a straight line except possibly those below 3 volts; such points may be ignored since the filament voltage is of the same order of magnitude as the accelerating voltage V. It follows that the intercept of this line on the voltage axis is equal to V_0.

The enormous reduction in space charge, due to the presence of positive ions, is shown by the following procedure. The bulb is removed from its cold bath and placed in warm water (25° to 40°C). The current-voltage characteristic is determined with the connections shown in Fig. 1; and then repeated with the plate circuit connected at y instead of at x. Fig. 2 represents two sets of data so obtained. The minimum ionization potential is the value of V, corrected for V_0,

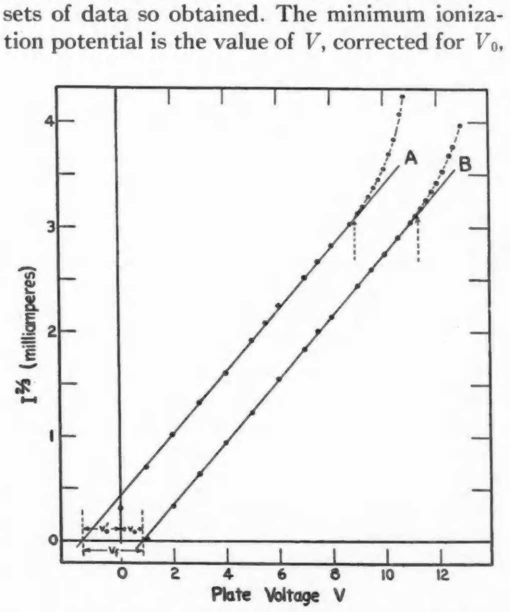

FIG. 2. Current-voltage characteristic, for bath temperature of 35°C. The ionization potential was found to be 8.9+1.4, or 10.3, volts from curve A and 11.3−0.8, or 10.5, volts from curve B.

[3] Child, Phys. Rev. **32**, 492 (1911); Langmuir, Phys. Rev. **2**, 450 (1913).

at which the deviation of the current from the linear relation first is apparent.

When proper precautions are taken this experiment yields a result for the ionization potential of mercury that is within 2 percent of the accepted value of 10.4 volts. However, if the water bath is too hot (above 75°C) the deviation of the current will occur at a potential 10–20 percent smaller than the accepted value. This discrepancy is probably due to successive collisions of an atom with two electrons of small kinetic energies, yet the sum of which is greater than the ionizing energy of the atom. The values of the mean-free-path at the higher temperatures give support to this hypothesis.

Finally, the student should calculate the mean-free-path of the electrons in the mercury vapor for the temperature at which the data were taken. For this calculation the student may obtain from tables the vapor pressure of mercury at the given temperature, and assume the pressures of any other gases in the tube to be negligible in comparison with that of the mercury. A similar calculation can be made for the case in which the bulb is immersed in ice water; if immersed in liquid air the pressure of other gases may no longer be negligible in comparison with that of the mercury, and it will be necessary to estimate a value for the total pressure in the bulb. Incidently, the comparison of the mean-free-paths with the plate-filament dimensions of the tube may be of interest to the student.

Teaching Aids

Booklets

Leeds & Northrup "Notebooks." *Leeds & Northrup Co.* (Philadelphia), gratis. No. 2–1930, *Notes on Moving Coil Galvanometers*, 46 p., 10 fig. No. 3–1931, *Notes on Hydrogen Ion Measurements*, 47 p., 12 fig. No. 4–1929, *Notes on the Kelvin Bridge*, 35 p., 11 fig.

Diesel—the Modern Power. 31 p., 53 fig. *General Motors Co., Research Laboratories Sec., Tech. Data Dept.* (Detroit), gratis. History of Diesel engine. Very simple explanations of its operation and how it differs from the gasoline engine. Good diagrams.

A Low Cost Electrical System for Farms. R. G. Kloeffler, J. L. Brenneman, O. D. Hunt. 15 p., 8 fig., 1 table. Extension Cir. 117. *Kansas State College Extension Div.* (Manhattan), gratis. Describes a tested home-assembled low-voltage system of low initial and operating costs. A low-capacity generator, gasoline engine or windmill, and two 80-amp.·hr. auto-type secondary batteries are employed.

Motion Picture Films

Alternating Current Motor. Silent, 16 mm, 40 min., 3 reels. *Otis Elevator Co.*, lent gratis from nearest Otis office or Publicity Division, 260 Eleventh Ave., New York. Shows the pouring of the castings, machining, boring, coil making, assembling, testing, etc., of a small elevator motor. Send for Form 1934 which describes other Otis films showing important engineering projects.

The International Harvester Diesel. Sound, 16 or 35 mm film, 33 min. International Harvester Co., Adv. Dept. (Chicago), loaned gratis. Close-up views and animated drawings of the fuel pump, valves, gears, cams, fuel filtering, oiling system, starting device, etc., of this Diesel engine.

The Kentucky Chapter of the A. A. P. T.

The Kentucky chapter of the A. A. P. T. has chosen the following subjects as themes for the meetings during the current year: "Teaching with a Forward Look," April 18, at Louisville; "Research in Kentucky Laboratories," May 9, at Bowling Green; "Physics and Industry," autumn meeting. The meeting held on January 11 at the University of Kentucky was devoted to a symposium on "The Progress of Physics in 1935." Professor L. A. Pardue, University of Kentucky, spoke on "New Theoretical Developments"; Professor J. G. Black, Morehead State Teachers College, on "New Experimental Procedures"; and Professor R. A. Loring, University of Louisville, on "The New Textbooks." Professor Bertrand P. Ramsay, University of Kentucky, is secretary of the chapter.

DISCUSSION AND CORRESPONDENCE

A Modification of the Traditional Approach to College Physics

IN a previous communication under the above title[1] the writer undertook to give an account of a reformulation and extension of a first-year college physics course with which he had been experimenting. The present note extends that communication and is suggested by the informing survey of Survey Courses in the Natural Sciences by Dr. Havighurst.[2]

Formally, at least, the course with which the writer is experimenting might seem not to be included in the classification of Dr. Havighurst, which specifically excludes " 'cultural' courses in separate sciences which sometimes go under a name such as 'survey of physics.' " On the other hand, the prominence of the historical approach and the extent of the philosophical excursions, as described in the previous communication about the course, would seem to necessitate classifying it as one "which draws its subject matter from two or more of the ordinary college departments," a circumstance that might indicate the appropriateness of its inclusion. In any case, it is to be hoped that Dr. Havighurst may take advantage of his excellent opportunities for observation in this field to provide the "separate treatment" which he intimates is deserved by certain types of course not specifically included in his former study.

It has been very easy for men of science to adopt a critical attitude toward the professional pursuits of certain of their colleagues; for example, toward those in the classics, philosophy and education. The writer pleads guilty to his share of such criticisms, and must even confess his inability to see any occasion for retracting anything he may have said when in such a mood.

He is fully aware, however, that as a prelude to all such criticism, he will do well to look to the order of his own house. No one who is guided by the inevitable implications of the adage that "Physics is physics" is in a position to cast reflections on the corresponding conviction of the classicist as to the disciplinary value of his subject. No one who has any familiarity with the development of human thought can fail to see that many contemporary men of science, especially some who are attempting to interpret science to the general public, are adopting fundamental philosophies that earlier generations of philosophers have conclusively demonstrated to be quite untenable and fallacious. And equally with the foregoing, no one who is associated in a teaching capacity with an educational institution can afford to be uninformed on current educational doctrines, even if only to have an adequate basis for rejecting them.

College students of the present generation are in some ways more sophisticated than in former times, and this is especially true in the way they make selections from the curriculum. The increased variety of curricular offerings, with its natural accompaniment of competition for student patronage, has begotten a "sales resistance" that is putting pedantry at a deserved disadvantage. The more discriminating students are well aware of many of the logical inconsistencies that characterize pronouncements of many men of science. They are impatient with the supercilious attitude of "pure" science or they hold applied science responsible for much of the economic and social distress of the world, each according to his temperament. They take the contributions of science to technology, medicine and the like as a matter of course, without being thereby necessarily attracted to the sciences as were their Victorian predecessors. That the sciences have passed their zenith as curricular subjects in colleges of liberal arts is strongly indicated by statistical studies on student registrations. If they are to retain a deserved and appropriate place in the curricular offerings of colleges and universities, they must broaden the base of their operations.

It is not the writer's intention to repeat here the description of the way in which he is undertaking to reformulate his own teaching material to this end. His previous description should suffice, even though it is somewhat superseded by present practice. Partly on the basis of close observation of such ventures, and partly on general principles, he feels that attempted syntheses of several sciences into one course are often of questionable wisdom at the college level, whatever may be said of analogous ventures in the field of secondary education. The present attempts to accomplish the desired results within the framework of existing curricular organization, though with major modifications, is one alternative which has seemed worthy of experimental development.

Men of science will quite naturally, and probably correctly, feel that a thorough mastery of the main aspects of a fundamental science furnishes the most secure foundation for an approach to the philosophical problems growing out of the sciences in general. The present experiment[1] accepts this as an axiom, though the attempt to work out its implications is involving some deviations from the subject matter commonly considered orthodox for such mastery. The problem of correlation of subject matter as thus extended, including a somewhat closer correlation of laboratory work and demonstration lectures with the main thread of the course than is usual, in addition to the added correlation rendered necessary by the wider ramifications of subject matter is, of course, the principal pedagogical problem in this experiment. It is receiving the degree of study and attention that its importance merits.

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Oberlin, Ohio.

[1] L. W. Taylor, Am. Phys. Teacher 1, 68 (1933).
[2] R. J. Havighurst, Am. Phys. Teacher 3, 97 (1935).

Another Method of Ranking Students According to Achievement in General Physics

OF all the tasks that fall to the lot of the teacher of physics one of the most disagreeable is the duty of assigning grades. Under the present academic policy prevalent in America this duty seems to be unavoidable and like most very onerous and uninteresting tasks, is often disposed of in the least troublesome and time-consuming manner possible. It is easy to become so absorbed in more interesting projects that the task of grading papers appears to be a wanton waste of time.

In dealing with large groups of students in general physics the most reliable information is derived from written tests which are so numerous, so diversified in subject matter and so distributed in time that the effect of such factors as temporary ill health or unusual emotional stress at the time of any one test may be eliminated. Were it practicable to eliminate grades, we should still prefer to give such a series of tests purely for instructional purposes. The motivation for study in this case would then be on a much higher level. As a practical matter we know that the student actually gives most time and thought to the course in which tests are used for grading as well as for instruction, and for economy of time we therefore devise all of our tests with both objectives in mind.

The current general practice is to employ one of three types of tests: a test made up entirely of problems; a combination of essay-type questions and problems; or the objective type which samples quite adequately the subject matter covered but fails to put in evidence certain other abilities which the student should acquire. The objective type measures both factual knowledge and the reasoning ability of the student but fails to yield information on his understanding of the step by step development of great principles and their correlation to other principles. It does not test his ability to describe the operation of certain types of engines and electrical machines, or such processes as the measurement of the speed of light.

Even the most experienced teacher cannot fairly estimate the time needed by a class to stand a given test and in the customary method of ranking, a serious mistake is made if the test is either too hard or too easy. It is a serious injustice to the student when a test either misleads an instructor as to his own achievement in teaching or gives the student an erroneous impression of his growth and mastery of the subject. It is disconcerting, but helpful, to a student to realize as he goes along how much of the course he is not mastering—provided, of course, the disclosure does not cause him to throw up his hands in despair. It is also helpful to a teacher to know as soon as possible how much he is failing to "put across."

After a number of years of experience with all types of tests, we, at Duke University, have settled on a procedure for general physics that makes liberal use of both the essay and comprehensive types. For our mid-semester, hour tests,—usually three in number—we use comprehensive short-answer forms. For "pop" tests, which take 10–15 min., we use the essay type, so graduated in difficulty as to aid us in classifying our students; these tests are usually given weekly.

Each question of a test is assigned a certain valuation in terms of points. Problems involving two or more steps in their solution are given separate valuations for each part so that partial credits are earned. Uusally 8 or 10 assistants work simultaneously in correcting papers and one assistant scores only a small section of the test through all of the papers; this aids in accuracy of scoring, enables the grader to maintain a definite scale of comparison and prevents the personal bias of any instructor from operating to the advantage or disadvantage of a given student. Every blank bracket on the test paper is marked by a colored line, so that after the paper is returned to the student for study he may not enter a correct answer and claim a correction. Items about which some question is raised as to scores are discussed with the students and corrections are made when justified. The total number of points that may be earned in one semester is about 500. A plot like Fig. 1 is made of the scores of the 250 to 300 students who take the course. All scores of the same magni-

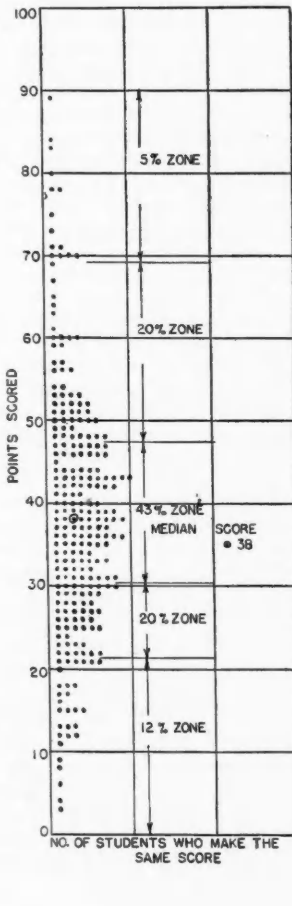

FIG. 1. The zones enable the student quickly to locate his position in the class. They do not give his grade.

tude are represented by dots on one horizontal line, the lowest grade being on the bottom line. The distribution in the specimen record shown is approximately normal. After each mid-semester test both the rank for that test and the term rank to date are published on the bulletin board.

After the final examination, the first step is to prepare a failing list. Several considerations are involved here. In the preparation of the tests certain questions are set to represent the minimum which we expect a student to know in order to pass. Thus we make it possible for one student to pass with a lower score than that of one who fails. The student who passes must show a mastery of certain fundamental principles. In general, we find it unnecessary to pass anyone who has answered correctly less than half of the total number of questions asked during the term. Toward the middle of the term the students at the bottom of the score column are given special interviews to test their ability to give an oral account of themselves. The search light is turned on and these cases are studied from every angle. No certain percentage of the class must fail and it is theoretically possible for the entire class either to fail or to make the highest grade, *A*. Those who fail are eliminated from further consideration. A grade of *C* is given to those whose scores lie in the bulge of the curve; this group usually constitutes about 43 percent of the students. Approximately 20 percent above and below this group are awarded *B* and *D*, respectively. Since ranks are published monthly, the students know just where they stand in the class, and those who find themselves near the bottom realize their danger. Actual grades are not awarded until the end of the term. No upset is made if one test is too hard or too long since the relative standing of students in the column will not be changed. If the student has mastered any part of the course he has an opportunity to demonstrate the fact and the letter grades are determined not by absolute figures, but by relative standing. In the operation of this method, as with all others in which the student is informed as to his exact numerical grade for the term, we must contend with the individual who fails to see why he is not given a *B* when his score is only one point below the division line. It is generally possible to locate these lines of demarcation where there is a distinct gap in the graph.

We have used this plan for more than ten years and have ample evidence that it works to the satisfaction of both staff and students. In Duke University, general physics is entirely elective for all except the premedical and engineerings groups. Out of a total enrollment in Trinity College of 1702 in September 1935, 291 registered in general physics. This is true despite the fact that the time census of student work hours taken by the Dean in 1934–35, revealed that general physics was rated among the leaders in the time of preparation per credit hour earned.

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A Rapid Method of Approximating the Area of a Hysteresis Loop

In connection with the experimental determination of the magnetic properties of irons and steels, it is customarily required to determine the area of the hysteresis loop and then the energy loss. The student may determine the area either with a polar planimeter or by some graphical method such as counting squares on the graph paper or determining an average ordinate. In the use of such methods gross errors often are made, for example in conversion of scales or in planimeter constant, and some rapid method of checking the area approximately is useful to the instructor. A rough empirical relation, which I have observed and which is good enough for the purpose

TABLE I.

Materials	H_{max}	B_{max}	Coercive Force	4× Coercive Force × B_{max}	$\oint HdB$	Percent Error
Steel wire	43.91	17680	7.71	545240	575170	−5
	21.89	15040	7.06	424730	431400	−2
	13.66	12070	6.48	312850	294810	+7
Soft sheet iron	32.34	15920	2.10	133730	175430	−24
	14.62	13730	2.10	115320	128620	−10
	8.05	11340	1.96	88960	91357	−3
Swedish iron wire	12.34	11330	4.83	218890	207210	+6
	7.30	7730	4.20	129860	113720	+14

and easy to apply, is as follows: $4\times \textit{coercive force}\times B_{max} = \oint HdB$, or the area of the loop is four times the product of the coercive force and the maximum flux density. This is merely a statement of the fact that the rectangle having as width the maximum width of the loop, and as height its maximum height, has nearly the same area as the loop. Table I exhibits this relationship for a few cases taken from Ewing and Klaasen[1] where a considerable amount of careful data on hysteresis are collected. It will be seen that the error is usually under 10 percent. While it is possible to find examples where the error is greater, for ordinary test materials and for moderate values of H the error is in fact rarely much more than 10 percent.

This relation is mentioned in the foregoing or equivalent form in Dubois,[2] and in Spooner,[3] but is given little space because of its approximate character. Its accuracy is adequate for check purposes, however, and its simplicity makes it so easy to apply that I think it worth calling attention to in the hope that others also may find it useful in detecting errors in hysteresis energy-loss determinations.

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[1] Ewing and Klaasen, Phil. Trans. Roy. Soc. **184**, 985 (1893).
[2] Dubois, *The Magnetic Circuit in Theory and Practice* (Longmans, 1896), p. 230.
[3] Spooner, *Properties and Testing of Magnetic Materials* (McGraw-Hill, 1927), p. 21.

Mass and Force as Kinetical Concepts

IN treating the concepts of mass and force, many elementary and advanced textbooks still adhere rather closely to the order and form in which these concepts were developed historically. Such an approach of course has its value. It is extremely important for the student to realize thoroughly that physics does not come into existence ready-made; that many of the initial steps in new discoveries are false, and the concepts growing out of them vague and faulty; that theories rarely achieve the simplest, most elegant form in their first development. The student should come to appreciate the enormous step that Newton took when he conceived the necessity for a concept of mass, different from weight, and for a kinetical concept of force; and to see that there is nothing extraordinary about Newton's failure to formulate his dynamics of particles in its final, most finished form. It is revealing, and stimulating, to find that Newton applied some of these concepts better than he defined them; that nowhere in his works is there an explicit definition of inertial mass; that some statements initially regarded as laws in his theory have turned out to be definitions.

But if this is to be our initial approach, let us be clear about what we are doing. If the idea of mass is introduced to the beginner with the statement that it is "a measure of quantity of matter," or that it is "measured matter" (one textbook states that it is the "cause of inertia") let us not pretend that such statements constitute physical definitions, or even that they have very much meaning, but that they are given for their historical interest and in an effort to strengthen one's intuitive grasp of the concept. To be sure, in an elementary or intermediate course it is not always possible or desirable to give the *best* definition of a concept, or the most rigorous form of a theory. Doubtless, this is why many textbook authors have hesitated to make use of Mach's well-known formulation of classical particle dynamics although it was adopted in such important treatises as those of Kirchhoff, Boltzmann and, more lately, Whittaker. But to my mind the elementary textbooks that use the modern approach, or some modification of it, do so with great improvement over the traditional presentation.

The method briefly outlined here is intended to present these kinetical concepts in as logical a manner as seems to be possible if one is at the same time to remain within the experience and capacities of the beginner. Any little novelty that the method may possess is not in the apparatus described but in the order of presentation and relative simplicity of the ideas.

We begin by stating, for the case of two particles, the experimental law that is the essence of Newtonian dynamics: if two, given, isolated particles interact in any way—whether gravitationally, electrically, magnetically, because of an elastic connection, or by colliding—and if we measure (relative to an inertial system) the changes in velocity Δv_1 and Δv_2 which the two given particles undergo during the interaction, it will be found that the ratio $\Delta v_1/\Delta v_2$ is a constant. If desired, this law may be illustrated with the help of two test bodies connected in turn by various springs.

Since $\Delta v_1/\Delta v_2$ is by experiment constant for a given pair of particles, an arbitrary number m_1 may be assigned to the one particle and a corresponding number m_2 defined for the other by means of the equation $\Delta v_1/\Delta v_2 = -m_2/m_1$. The numbers m are called the masses of the particles. Incidentally, by defining momentum at this point, our equation is seen to express conservation of momentum.

The student now can carry out the operations implied in the foregoing definition and hence measure masses by a direct method. This may be done in several familiar ways, say with a pair of cars running with little friction on a straight, horizontal track. An unattached compressed spring placed initially between the cars acts upon both of them for the same short time, after which they travel away from each other with constant, easily determined velocities v_1 and v_2. Thus the masses of the cars and of various objects placed in them may be measured.

This method of defining mass has the well-recognized logical advantage that it does not involve force explicitly. What also should be appreciated is that it introduces the student to the concept of mass without mixing it in his mind with force and weight, a great pedagogic advantage. Moreover, the method as it is developed here does not explicitly involve acceleration, a concept which in its quantitative aspect is not familiar to the beginner, or easy to measure. It is not to be pretended of course that this is the most practical method of measuring mass. But the beam balance, which ordinarily is used, measures directly so-called gravitational mass. Only by the performance of an additional experiment can the equivalence of inertial and gravitational mass be established. This cannot be done simply by using the same symbol m in Newton's law of gravitation and the laws of motion which actually is as far as some textbooks go in the matter.

The student is now ready for the kinetical concept of force. To keep the treatment from becoming too abstract, he is reminded that force was first developed as a scientific concept in statics and that there one body is said to exert a force on another with which it is in contact if its removal results in a change of position of the second body, and that experience shows that the same effect on the second body can be obtained by means of springs or by weights and strings. This statical definition is quite independent of any notion of mass.

With this preliminary discussion we are ready for an experiment. Numerous familiar devices may be employed but for this discussion we will use a horizontal track, one car and a weight attached to the car by a thread passing over a pulley, an apparatus which has the advantage that it involves only one propelling agent. As before we shall pass over such matters as correction for friction, etc. A mass m_2 is attached to the thread and thus the system of known mass (m_1+m_2) is set in motion. By means of a stopping surface placed under m_2, or by burning the thread, m_2 is removed from the system at the end of a measured time t, and from then on m_1 moves with a constant velocity v which also is measured. Repeated trials in which the time t is varied will show that the final velocity acquired by the car is proportional to the time that the propelling agent acts; that is, $v \propto t$, as long as m_1 and m_2 are the same.

Next the total mass m of the system is changed by changing m_1, but not m_2, and m_2 now is allowed to remain a part of the system always for the same time t. Repeated trials will show that the final velocity acquired is inversely proportional to the total mass set into motion; or $v \propto 1/m$, as long as t and m_2 are constant.

Combination of these two experimental relations gives $v \propto t/m$, or $mv/t = const$, as long as the propelling agent is not changed. This result leads us to define force as proportional to mv/t. That the definition is reasonable and useful will be apparent to the student, for he knows that m_2 has weight and the experiment shows that as long as this weight is not changed, mv/t remains the same; time rate of change of momentum is the proper quantity to associate with the action of weights and other forces. To have come out with this definition, rather than with the less fundamental $f \propto ma$, as Mach did, obviously is advantageous.

Because the method has been presented here in a condensed form, it may seem to be too abstract, formal and nonintuitive in character for use with immature students. From my own experience, however, I am convinced that this outline, when properly amplified and augmented with good illustrative material, can be used with great success in the standard first year course by any teacher who is willing to adopt whole-heartedly the point of view expressed.

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Color Mixers

JOHN J. HEILEMANN'S interesting note [Am. Phys. Teacher **3**, 184 (1935)] prompts me to describe a similar color mixer in order to point out the pedagogic value of a certain procedure in carrying out the demonstration. The apparatus in question was devised by H. A. Erikson at the University of Minnesota some twenty-five years ago for illustrating complementary colors and hence uses but two filters and two mirrors. The filters, consisting of plane glass absorption vessels about 1 cm thick, one filled with a solution of copper sulphate and the other with a solution of ferric chloride, are placed side by side before the condenser of the projection lantern. An opaque screen with two circular openings about 1.5 cm in diameter covers the filters and these openings are projected onto a screen after the light coming from them has been reflected by the mirrors placed in front of the projection lens. The mirrors, 7×8 cm, are carried by a common frame and one of them has a hinge at its line of contact with the other mirror so that its relative angular position may be changed by means of an adjusting screw. The two colored images, one blue and the other a brownish yellow, first are projected so that they lie side by side on the screen and then are made to overlap partly by gradually tilting the movable mirror, when the resulting color is seen to be white. This minor detail of seeing the mixing of the colors, as it were, before one's eyes is what adds much to the impressiveness of the experiment.

The difference between the color obtained by the mixture of the colors of two pigments and the color shown by a mixture of the two pigments may next be illustrated by projecting the two absorption vessels directly upon the screen after the perforated screen and the mirrors described have been removed. The two vessels are then made to overlap partly and the resulting color, now dark green, shown. Or what is more impressive still, the solution from one vessel may be poured into the other solution and the two liquids actually mixed while under observation.

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Diatonic Scales

IN some recent textbooks the term *diatonic scale* is used as synonymous with *just scale*. This use of the term seems so unfortunate as to call for remark. For many years it has been customary to distinguish between "diatonic" scales—which usually proceed by steps and half steps—and a "chromatic" scale which proceeds by half steps. When the term "diatonic" is employed with this customary meaning it is of some value, and at least has significance. I suppose the term "diatonic scale" is today more often used with reference to a tempered scale than to a just scale, but when the term is employed to mean the same as "just scale" it seems to me that it loses all significance.

The authors who have recently employed the term as an equivalent for "just scale" have probably done so because this use of the term was unfortunately suggested by definition 4016 in the "Report of the Committee on Standardization of the Acoustical Society of America."[1] But in Murray's *New English Dictionary*, Webster's *New International Dictionary* (1934) and Grove's *Dictionary of Music and Musicians* (ed. 3) I find no justification for this use.

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[1] J. Acous. Soc. **2**, 318 (1931).

The Second International Congress for the Unity of Science

AT the Second International Congress for the Unity of Science, which will take place in Copenhagen, June 21–26, 1936, the central topic will be the relation of physics and biology, including psychology, with especial emphasis upon the concept of causality. A small number of invited speakers will provide the context for a general discussion. Niels Bohr will participate in the congress. Inquiries and notices of intended attendance may be directed to the Secretary, Dr. Otto Neurath, Mundaneum Institute, 267 Obrechtstraat, The Hague, The Netherlands.

Recent Publications

First Year Textbooks and Manuals

College Physics. C. E. Mendenhall, late Professor of Physics, University of Wisconsin, A. S. Eve, Macdonald Professor of Physics, and D. A. Keys, Professor of Physics, both of McGill University. 592 p., 546 fig., 30 tables, 15×22 cm. *D. C. Heath*, $3.76. A presentation in the traditional manner and the usual divisions, but with 30 additional pages on the new physics. Dynamics precedes statics. The c.g.s. and f.p.s. systems are made basic in the treatment of mechanics, but gravitational units also are employed and illustrated adequately. The gravitational units of force quite properly are referred to as the *pound weight, gram weight*, etc. The modern practice is followed of employing negative exponents in the abbreviations for units; e.g., $cm \cdot sec.^{-2}$. Many of the more difficult sections are starred. Although the arrangement and treatment are conservative, modern concepts and terminology are employed and modern applications are described throughout the text.

Exploring in Physics. Reginald J. Stephenson, Ryerson Physical Laboratory, University of Chicago. 205 p., 17×23 cm. *Univ. of Chicago Press*, paper, $1.50. A book of unusually interesting problems, worked examples and introductory text material, intended to supplement Professor Lemon's *From Galileo to Cosmic Rays* [see Am. Phys. Teacher **3**, 92 (1935)] and to provide with the latter adequate material for a full year's course. To enable the student to attack more complex problems than otherwise might be possible, many of the problems are so subdivided that the answer to one part may be suggested by the preceding step. The many diagrams and drawings are attractive and mostly original.

An Outline of First Year College Physics. Clarence E. Bennett, Assistant Professor of Physics, University of Maine. 159 p., 117 fig., 14×21 cm. *Barnes & Noble*, paper, 75 cts. Whatever one's opinions might be of the pedagogic value of "self-help" and review outlines, the present one is so much above the average that it deserves special attention. Really it is not an outline but an intelligently planned, sound digest of the essential contents of a good first year course. It contains many diagrams, a quick-reference table to important topics in 15 well-known first year textbooks, review questions at the ends of the chapters, a brief appendix of tables and constants, and an index. This is one of the "College Outline Series."

Experimental Physics. Edwin Morrison, Assistant Professor of Physics, and S. Elizabeth Morrison, Instructor in Physics, Michigan State College. 365 p., 189 fig., 22×28 cm. *Blakiston*, paper, $2. The authors of these "study problems" for the general laboratory take the position that it is not necessary to emasculate physics in order to make it popular; that the problem is to awaken the beginner's interest and with this accomplished, rigorous and real physics can be taught without rendering the course unpopular. They consider the objective of the general laboratory to be the acquisition of a physics technic; that is, the ability to observe, to set up experimental conditions, to manipulate mechanisms, and to organize and formulate one's mental processes in accordance with nature. In each of the 65 experiments in the book, the theory is given considerable emphasis. A knowledge of calculus is not needed for the course, although it is used in a few places. A data sheet, in duplicate and perforated for detaching, appears with each experiment. There is no index or table of contents.

Elements of Heat. L. F. Miller, University of Minnesota. 106 p., 87 fig., 21×27 cm. *Burgess Pub. Co.*, mimeographed, $1.90. A conventional, elementary treatment consisting of 10 chapters, one of which is devoted to thermodynamics. The problems are relatively simple.

Laboratory Manual of Physics. A. A. Knowlton, Professor of Physics, and Marcus O'Day, Assistant Professor of Physics, Reed College. Ed. 2. 137 p., 67 fig., 15×23 cm. *McGraw-Hill*, $1.25. This manual has been revised and corrected to conform with the order of topics in the new edition of the senior author's textbook [see Am. Phys. Teacher **3**, 139 (1935)]. The authors point out that physics has an unenviable reputation for difficulty and that this "difficulty is often charged to 'mathematics,' whatever that may mean." But an analysis of student difficulties seems to the authors to indicate that these difficulties really are due mostly to the multitude of new concepts to which the beginner is unavoidably introduced at the very outset. These concepts are new not only individually but in kind, for most of them are metric in character; that is, they are defined by the methods used to measure them. "Herein lie the necessity and the justification for quantitative laboratory work. A laboratory is a place for the acquisition of those metric experiences which are a necessary background for metric concepts. . . ." With these ideas in mind the authors have provided several times as many exercises as are needed for the average student; these vary greatly in difficulty and cover a considerable range of concepts. Much assistance is offered at the beginning and less later. Requirements of technic are minimized; "The test of success in an exercise lies in the clearness of the student's ideas when it is completed rather than in the numerical accuracy of his results."

Intermediate Textbooks

Sound. Floyd Rowe Watson, Professor of Experimental Physics, University of Illinois. 219 p., 175 fig. and tables, 15×23 cm. *Wiley*, $2.50. Most of the chapters of the book begin with a simple illustrated discussion and this is followed by a more detailed but elementary mathematical treatment. Hence the book is suitable both for the able reader who wants a non-mathematical treatment and for the non-science major who has had some general physics and trigonometry. More advanced students can make use of the annotated list of references given for further study. This book also should be exceedingly useful as

reference for general physics; the treatment of sound is more comprehensive and detailed than is possible in a general text, but the grade of difficulty and modes of approach are much the same. Especially effective and useful are the chapters on diffraction, the Doppler effect, acoustics of rooms, and speech and hearing. The 21st, and last chapter outlines 19 experiments suitable for demonstration or the laboratory. Lists of good descriptive and quantitative problems accompany the chapters. Many of the excellent illustrations are original.

Advanced Textbooks and References

Introduction to Theoretical Physics. Leigh Page, Professor of Mathematical Physics in Yale University. Ed. 2. 661 p., 210 fig., 15×23 cm. *Van Nostrand*, $6.50. Many students and teachers who have used the first edition of this book will testify to its usefulness in providing a general introduction to theoretical physics, particularly classical theory treated in terms of vectors and dyadics. The new edition has 74 additional pages and includes a list of references for collateral reading, some new problems, and 15 new articles, one of which is on quantum mechanics. The index has been improved.

Modern Acoustics. A. H. Davis, The National Physical Laboratory (England). 345 p., 104 fig., 8 pl., 15×23 cm. *Macmillan*, $6.00. A survey of acoustics for students and technical and research workers in which the subject matter has been selected with an eye for what is important in this field as it is practised today. It begins with the theory of vibrating systems and deals in turn with sources of sound, modern methods of measuring pitch and intensity, and the idea of acoustic impedance, with its numerous practical applications. Electrical apparatus and methods are stressed. There are "some omissions—as, for instance, the theories of the vibrations of strings and bars—of material usually dealt with in elementary textbooks . . ., but which have little special significance in modern developments."

The Theory of Atomic Spectra. E. U. Condon, Associate Professor of Physics in Princeton University, and G. H. Shortley, Instructor in Physics in the Ohio State University. 441 p., 69 fig., 35 tables, 17×26 cm. *Cambridge Univ. Press* and *Macmillan*, $11.00. This comprehensive and well-organized deductive treatment of the structure of atomic spectra in terms of the principles of the quantum mechanics provides a good example of what can be done for the literature of advanced physics when the authors not only understand their subject but are able and willing to take seriously the responsibilities of authorship. The treatment is unified and not simply a collection of material taken bodily from the source literature. It is written with a sense for style, a regard for good notation and terminology, and a critical eye for clearing up points that have been sources of confusion in the literature. The book opens with a very brief review of the principles of the quantum mechanics as formulated by Dirac. A knowledge of group theory is not needed. As the authors point out, the known features of atomic spectra have been explained at least semi-quantitatively but this does not mean the end of fruitful research in this field; the relativistic treatment of the many-electron problem and the theory of the interaction of radiation and matter involve unsettled questions of a fundamental nature, and there are many places where more data or better calculations are needed.

Miscellaneous

A Fugue in Cycles and Bels. John Mills. 269 p., 34 fig., 4 tables, 13×20 cm. *Van Nostrand*, $3.00. An instructive and stimulating book in a popular style for the intelligent music lover or the beginner in physics who wants to know what physics is doing for music. Among the subjects discussed are the characteristics of musical sounds, studies of hearing and their relation to musical reproduction and perception, electro-acoustical apparatus as aids in music teaching, and the use of new electrical technics in the production and modification of musical sounds. Mr. Mills not only writes well but he has good pedagogic sense and the knack for anticipating what will interest the layman. This book, like his other writings, exemplifies his beliefs that an intuitive rather than a logical order is preferable for an introductory presentation and that one not only should anticipate and answer the questions of the reader but should stimulate questions that the reader can answer for himself with a little help.

The American College and University. Charles Franklin Thwing, President Emeritus of Western Reserve University and Adelbert College. 244 p., 14×20 cm. *Macmillan*, $2.25. A college president of the old school describes the organization and work of private and state institutions, particularly the relation of their parts to one another and of the whole to the community. The essential thesis of the book is that the college is a human fellowship and in expanding on it the author has provided a compendium of practical advice on how to run a college and be a part of it. In a manner that often is delightfully pedantic but seldom dull, he specifies, among many other things, the proper qualifications for a member of the board of trustees, the ways to handle fraternities and athletics, and the technic for getting off jokes in classes. The book contains much practical wisdom and, for those who need it, provides inside information on what college presidents think about.

Back Numbers Wanted

DIGEST OF PERIODICAL LITERATURE

General Education

Productive scholarship in the undergraduate college. R. L. Jeffery; *Am. Math. Mo.* **42**, 364–9, June, 1935. In the colleges that are not a part of a larger institution having a graduate school, it is not even recognized for the most part that productive work has a definite place in the activities of the undergraduate teacher. Where this recognition does exist it is merely formal and an atmosphere exists that is uncongenial to the teacher interested in progressive scholarly work. Such a situation is so unfortunate that it seems worth while to attempt to show that a certain amount of productive work is essential to first-class teaching and that in every college active participation in scholarly work is practicable. This is no attempt to make out a case for research for its own sake but to show why the college teacher should have an active interest in research apart from the possible value of any results which he obtains. Since the word 'research' has become distasteful to many because of its application to no end of activities that are totally unrelated to anything scholarly, the term *productive scholarship* seems more fitting for present purposes.

In the type of colleges under consideration it is not feasible to consider the problem of productive work apart from its relation to all the other activities in which teachers must engage. But no matter what phase of these activities are considered, we find that it imposes a definite obligation to participate actively in creative effort. In the first place, in the elementary instruction which occupies so much of the time, there are parts of the work that do not seem to go over year after year. We tend to accept this as inevitable because of something inherently difficult in the work in question, or else let it go with the explanation that students nowadays are not up to what they should be. But the trouble is much more likely to be with our methods than with the work or the students, and once this fact is faced the problem resolves itself into one of creative effort. Such a problem requires thought, sustained effort and ingenuity; its solution is a source of satisfaction because obstacles are removed from places where we have come to expect our classes to be held up, to say nothing of the time and energy saved. Work at this level is valuable because the cooperation of the students can be secured. The work frequently leads to worth-while publication. Interest is heightened if the student can find in the literature what others are thinking on the same subject. These problems arising out of elementary teaching should be discussed much more freely in the journals.

Though there is by no means unanimity of opinion on the value of an interest in creative work, on one point there is universal agreement: a college teacher should know his subject matter. He should know its origin, significance and relation to other fields; and the point of view, methods and results of contemporary workers in his field. He should be so thoroughly aware of and awake to the subject that his enthusiasm carries over to the students. All this has been said many times. But it does not seem possible for one to appreciate fully any field of intellectual endeavor unless he is attempting original work in some phase of it. Even if it were possible, one cannot come anywhere near to the degree of excellence demanded, without at least being in a position to make some contribution. Once a person arrives at a full knowledge of any field of work, he necessarily sees some phases of it from a new angle and is in a position to suggest new lines of investigation, new or simpler methods of working, or correlations of the whole field in the light of his own peculiar training and experience. Unless he is willing to derive his satisfaction wholly from the hard work of others, he is obligated to do one, or all, of these things to the best of his ability; and if he does, he has broken through to a fairly high level of productive scholarship. If we fail to reach this level, either we must admit not having troubled ourselves to master our subject, and hence are unfit for our positions, or else we must acknowledge that our minds are closed to original ideas, or that we are too indifferent or indolent to make known such worth-while ideas as we do have. One or the other of these undesirable positions seems to be the only alternative to an active interest in productive work.

If the Honors work being featured by many colleges is in a healthy state, it will be under the direction of teachers who are themselves students and who are meeting their obligation to be actively interested in productive scholarship.

In truth there are fields of influence open to the teacher that are not directly related to instruction in his subject. Thus, there is the opportunity for close association between teacher and student, with all that this implies. It is in such ways as this that a teacher renders his most important service. But it must be done incidentally, and his influence varies directly with his own personal qualities of character and intellectual insight. And it is difficult to see how a teacher can keep his own intellectual tools at a keen edge unless he continues to submit himself to the hard discipline that creative work imposes.

Thus from every angle we find creative work one of the obligations, perhaps the main one, of the college teacher. One wonders why there ever should be any question about this, or why college administrators should fail to see it in this light. But fail they do, as is evident in the endless literature on the subject. How can students be expected to settle down to hard and serious study if those supposed to be their leaders have long since ceased from substantial intellectual effort? If there were no reason at all for our participation in creative work, other than the example of hard study that we set for our students, this would be sufficient.

To the practical question of whether conditions in the colleges make an interest in creative work at all possible, the answer is yes. In truth one cannot always do the sort of work that he would like to do, nor so much of it. But despite heavy teaching schedules and inadequate facilities, a working nucleus is soon accumulated if resources are concentrated in one or two fields. It might even be advisable to adapt one's interests to such equipment as there is.

If we believe the half of what we hear and read about our colleges, not one of them can in any sense be called a seat of learning. To become one is not so much a matter of size and resources, as it is of attitude and emphasis. These latter should be in the direction of creative work, at least so far as the faculty is concerned. Such things as organization, curriculum making and classroom procedure, which now hold the stage, are important but should by no means be the whole show. If the faculty and students work together with a real interest centered in one way or another in creative work in the sciences, the humanities and the fine arts, a way of living is achieved that is in the highest sense cultural. No other interest can serve as a unifying background and central purpose to accomplish this end.

Appointment Service

All correspondence concerning this appointment service should be addressed to the Editor, The American Physics Teacher, University of Oklahoma, Norman, Oklahoma.

Physicists Available

Representatives of departments or of institutions having vacancies are urged to write for additional information concerning the physicists whose announcements appear here or in previous issues. *The existence of a vacancy will not be divulged to anyone without the premission of the institution concerned.*

5. Man, 30, married, Ph.D. Yale. 6 yr. teaching experience in eastern universities in most branches of undergraduate physics for both men and women; 3 yr. research associate in radiology in prominent medical school. Supervision of master's theses; research in nuclear physics and thermionics. Broad interests.

6. M.S., N. C. State College; 5 summers grad. work, Univ. of Chicago. Age 39, married. 3 yr. instr. N. C. State College; 5 yr. asst. prof., 7 yr. assoc. prof., Woman's College, University, N. C. Interested in undergraduate teaching or technical research.

7. A.M., A.B., Princeton; 2 yr. additional grad. work in spectroscopy, Princeton and Columbia. Age 30, unmarried. 4 yr. instr. Univ. of Vermont. Special interest in teaching and in developing demonstration and laboratory experiments.

8. Man, 36, married. 15 yr. teaching experience in two eastern universities. Completing Ph.D. thesis in spectroscopy this year at Cornell. Undergraduate teaching experience: demonstration lectures, premedical physics, optics, atomic physics, astronomy, astrophysics.

9. Ph.D. Univ. of Minnesota; S.B., S.M., M. I. T.; 1 yr. grad. work, Univ. of Iowa. Age 38, married, 2 children. 17 yr. teaching experience in universities, colleges and technical schools, including 10 yr. head of department. Interested in progressive undergraduate and graduate teaching and research, including mathematical physics.

10. M.S., B.S., Louisiana State Univ.; 3 yr. graduate work, Cornell. Research in spectroscopy. Age 28, unmarried. 4 yr. instructor, Louisiana. Special interest in teaching and in developing demonstration and laboratory experiments.

Any member of the American Association of Physics Teachers who is not employed in a capacity that makes use of his training in physics may register for this appointment service and have a "Position Wanted" announcement published without charge.

Vacancies

Physicists who wish to be considered for research positions in the paper industry that may be available in the near future should send to the Editor a brief statement of personal data and professional qualifications. The research, broadly speaking, consists of studies of paper properties and of materials and processes involved in the preparation of pulp and the making of paper.

Departments having vacancies and industrial concerns needing the services of a physicist are invited to publish announcements of their wants; there is no charge for this service.

Available Graduate Appointments

University of Missouri, Prof. H. M. Reese, Columbia, Mo. 1–2 *graduate assistants*, half-time lab. teach., $600–700 less $60 t.

Exchange Appointments

A professor of physics, Ph.D., who has taught for many years in an Ohio college writes that he is seeking an exchange position for one year, preferably in a western college. Because the idea of exchange professorships in physics is important and for obvious reasons should be encouraged, the editorial office will undertake to act without charge as an intermediary for members of the American Association of Physics Teachers who wish to arrange exchanges for themselves. Send a brief statement of personal data and information concerning your departmental duties.